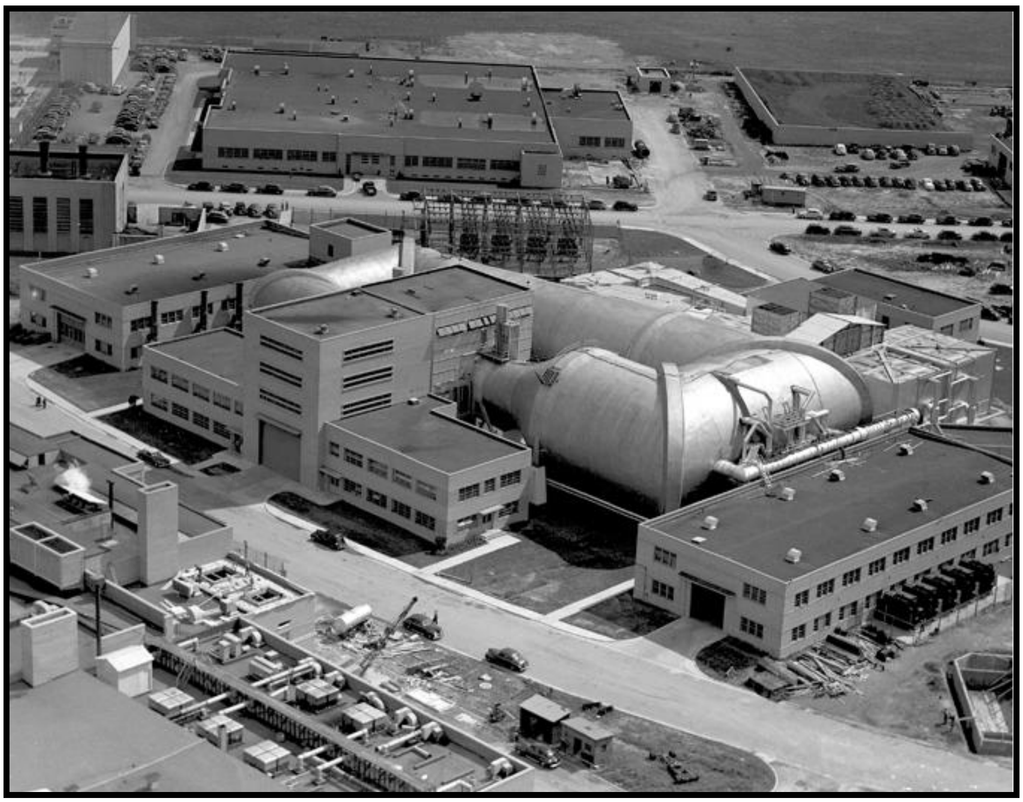
Historic American Engineering Record Documentation of the NASA Altitude Wind Tunnel and Space Power Chambers

NASA Glenn Research Center
Cleveland, Cuyahoga County, Ohio



February 2009

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Wyle Information Services,
NASA Glenn History Program

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ALTITUDE WIND TUNNEL
(Microwave System Lab—Building 7)
NASA Glenn Research Center at Lewis Field
Cleveland
Cuyahoga County
Ohio

Historical & Architectural Information:
Altitude Wind Tunnel
1941-58

WRITTEN HISTORICAL AND DESCRIPTIVE DATA

PHOTOGRAPHS

Bob Arrighi
Wyle Information Systems
NASA Glenn History Program

February 2009

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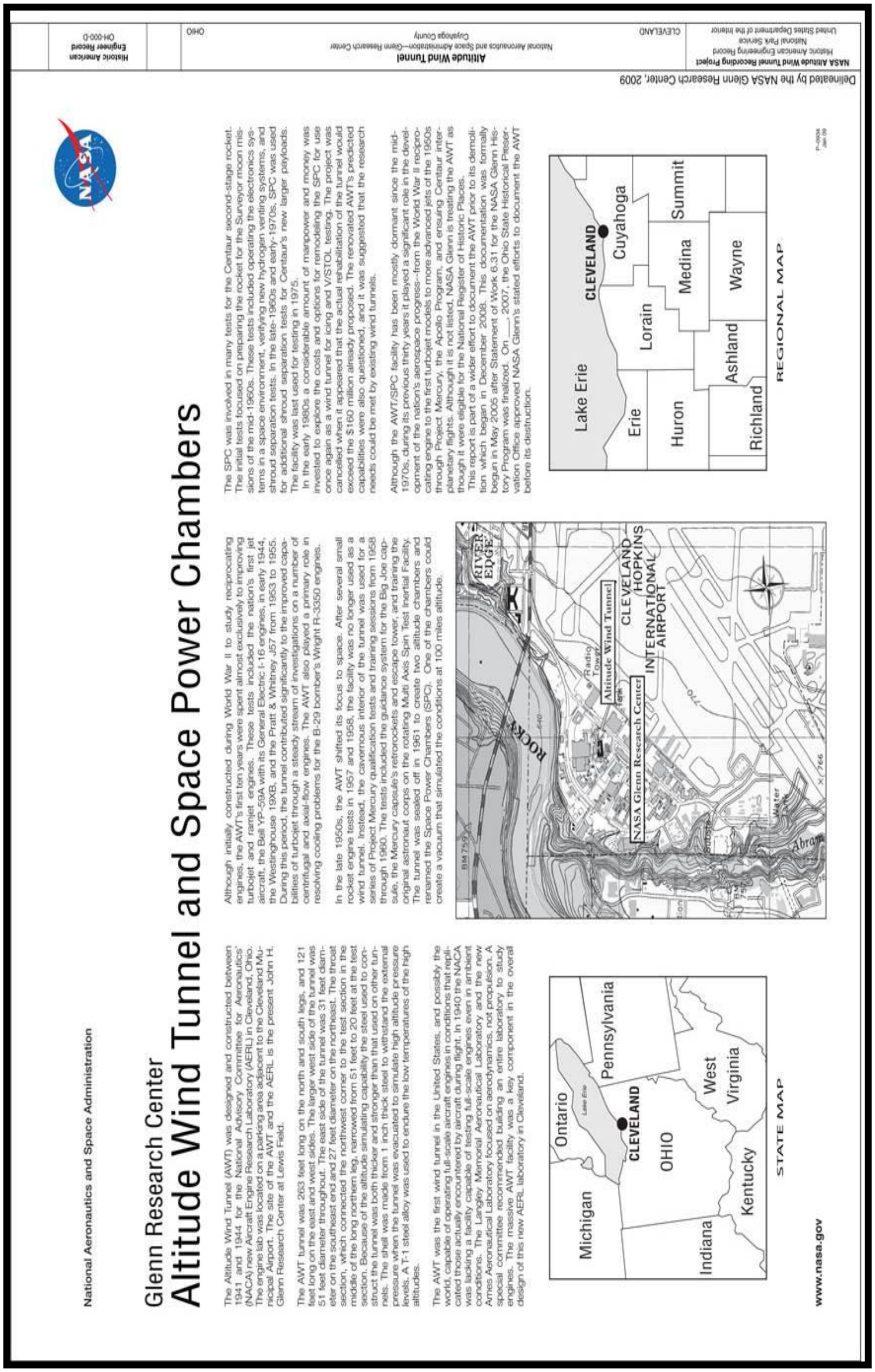

National Aeronautics and Space Administration

Glenn Research Center
Altitude Wind Tunnel and Space Power Chambers

The Altitude Wind Tunnel (AWT) was designed and constructed between 1941 and 1944 for the National Advisory Committee for Aeronautics' (NACA) new Aircraft Engine Research Laboratory (AERL) in Cleveland, Ohio. The engine lab was located on a parking area adjacent to the Cleveland Municipal Airport. The site of the AWT and the AERL is the present John H. Glenn Research Center at Lewis Field.

The AWT tunnel was 263 feet long on the north and south legs, and 121 feet long on the east and west sides. The larger west side of the tunnel was 51 feet diameter throughout. The east side of the tunnel was 31 feet diameter on the southeast end and 27 feet diameter on the northeast. The throat section, which connected the northwest corner to the test section in the middle of the long northern leg, narrowed from 51 feet to 20 feet at the test section. Because of the altitude simulating capability the steel used to construct the tunnel was both thicker and stronger than that used on other tunnels. The shell was made from 1 inch thick steel to withstand the external pressure when the tunnel was evacuated to simulate high altitude pressure levels. A T-1 steel alloy was used to endure the low temperatures of the high altitudes.

The AWT was the first wind tunnel in the United States, and possibly the world, capable of operating full-scale aircraft engines in conditions that replicated those actually encountered by aircraft during flight. In 1940 the NACA was lacking a facility capable of testing full-scale engines even in ambient conditions. The Langley Memorial Aeronautical Laboratory and the new Ames Aeronautical Laboratory focused on aerodynamics, not propulsion. A special committee recommended building an entire laboratory to study engines. The massive AWT facility was a key component in the overall design of this new AERL laboratory in Cleveland.

Although initially constructed during World War II to study reciprocating engines, the AWT's first ten years were spent almost exclusively to improving turbojet and ramjet engines. These tests included the nation's first jet aircraft, the Bell YP-59A with its General Electric I-16 engines, in early 1944, the Westinghouse 19XB, and the Pratt & Whitney J57 from 1953 to 1955. During this period, the tunnel contributed significantly to the improved capabilities of turbojet through a steady stream of investigations on a number of centrifugal and axial-flow engines. The AWT also played a primary role in resolving cooling problems for the B-29 bomber's Wright R-3350 engines.

In the late 1950s, the AWT shifted its focus to space. After several small rocket engine tests in 1957 and 1958, the facility was no longer used as a wind tunnel. Instead, the cavernous interior of the tunnel was used for a series of Project Mercury qualification tests and training sessions from 1958 through 1960. The tests included the guidance system for the Big Joe capsule, the Mercury capsule's retrorockets and escape tower, and training the original astronaut corps on the rotating Multi Axis Spin Test Inertial Facility. The tunnel was sealed off in 1961 to create two altitude chambers and renamed the Space Power Chambers (SPC). One of the chambers could create a vacuum that simulated the conditions at 100 miles altitude.

The SPC was involved in many tests for the Centaur second-stage rocket. The initial tests focused on preparing the rocket for the Surveyor moon missions of the mid-1960s. These tests included operating the electronics systems in a space environment, verifying new hydrogen venting systems, and shroud separation tests. In the late-1960s and early-1970s, SPC was used for additional shroud separation tests for Centaur's new larger payloads. The facility was last used for testing in 1975.

In the early 1980s a considerable amount of manpower and money was invested to explore the costs and options for remodeling the SPC for use once again as a wind tunnel for icing and V/STOL testing. The project was cancelled when it appeared that the actual rehabilitation of the tunnel would exceed the $160 million already proposed. The renovated AWT's predicted capabilities were also questioned, and it was suggested that the research needs could be met by existing wind tunnels.

Although the AWT/SPC facility has been mostly dormant since the mid-1970s, during its previous thirty years it played a significant role in the development of the nation's aerospace progress--from the World War II reciprocating engine to the first turbojet models to more advanced jets of the 1950s through Project Mercury, the Apollo Program, and ensuing Centaur interplanetary flights. Although it is not listed, NASA Glenn is treating the AWT as though it were eligible for the National Register of Historic Places.

This report is part of a wider effort to document the AWT prior to its demolition which began in December 2008. This documentation was formally begun in May 2005 after Statement of Work 6.31 for the NASA Glenn History Program was finalized. On ___, 2007, the Ohio State Historical Preservation Office approved NASA Glenn's stated efforts to document the AWT before its destruction.

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Delineated by the NASA Glenn Research Center, 2009

NASA Altitude Wind Tunnel Recording Project
Historic American Engineering Record
National Park Service
United States Department of the Interior

CLEVELAND

Altitude Wind Tunnel
National Aeronautics and Space Administration—Glenn Research Center
Cuyahoga County

OHIO

Historic American Engineer Record
OH-000-D

AWT Image 2: P0934NASA Glenn Research Center

Part I: Historical Information

The Altitude Wind Tunnel at NASA Glenn Research Center in Cleveland, OH
AWT Image 3: 2005-01492/NASA Glenn Research Center (2005)

View from the northeast of the Aircraft Engine Research Laboratory with the AWT at the center
AWT Image 4: 1945-013059/NASA Glenn Research Center (1945)

ALTITUDE WIND TUNNEL
(Microwave Systems Laboratory)

Location: National Aeronautics and Space Administration (NASA)
John H. Glenn Research Center at Lewis Field
21000 Brookpark Road
Cleveland. Cuyahoga County, Ohio

The facility is located in the wedge-shaped block of Ames, Moffett, Durand, and Taylor roads near the center of the Glenn Research Center. The facility's T-shaped Shop and Office Building faces north on Ames Road with the tunnel forming a rectangle behind.

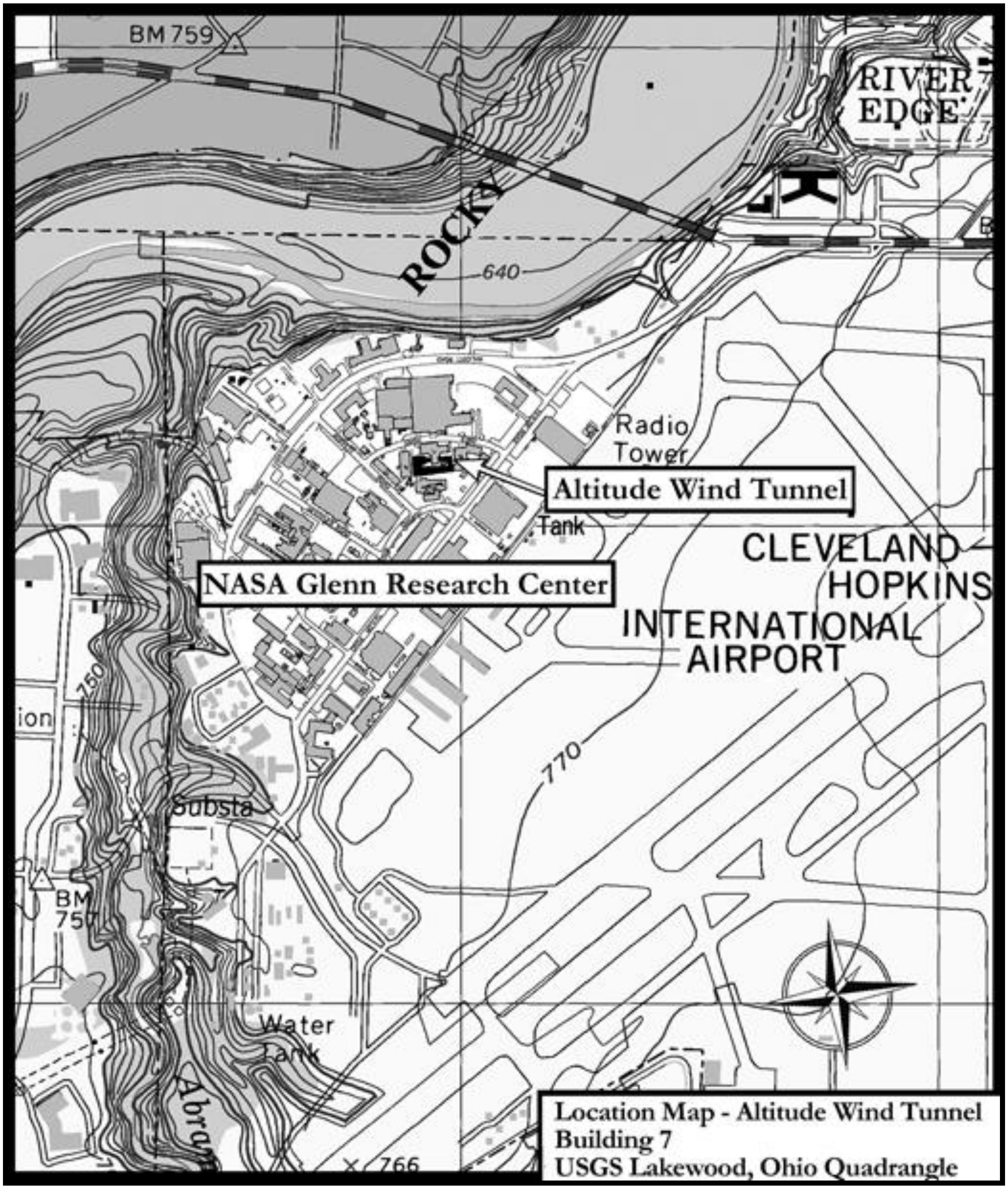
Elevations: The Altitude Wind Tunnel's southwest corner was 751 feet, south leg 755 feet, southeast corner 754 feet, northeast corner 755 feet, and northwest corner 752 and 735 feet. The Shop and Office Building (Building 7) was at 754 feet.[1]

UTM Coordinates: 17 427938E 4585154N (NAD83)
Latitude: 41.41471, Longitude: -81.86227
Quadrangle: Lakewood, Ohio

Present Owner: NASA John H. Glenn Research Center

Present Use: The tunnel's primary building, Building 7, is presently named the Microwave Systems Laboratory and contains near-field and far-field antenna testing ranges operated by the Communications Division. The office portion of Building 7 is used primarily as office space by the NASA Glenn Educational Programs Office. Building 7 was not included in the demolition of the tunnel.

In the 1990s and 2000s, the former wind tunnel test section has been used for storage by the Communications Division. Various large pieces of equipment are stored inside the test section, and the surrounding test chamber room is littered with excess equipment and supplies. The chamber's overhead crane remains in working condition and is used by the Microwave Systems Laboratory. The former tunnel control room on the mezzanine level has been gutted, and the space reconfigured as a storage room. The interior of the wind tunnel itself had not been used as a test facility since the mid-1970s. Its interior was used as a storage area. Demolition of the tunnel shell and its supports is scheduled to begin in 2008.



Location Map for Altitude Wind Tunnel – Building 7
AWT Image No. 5/NASA Glenn Research Center

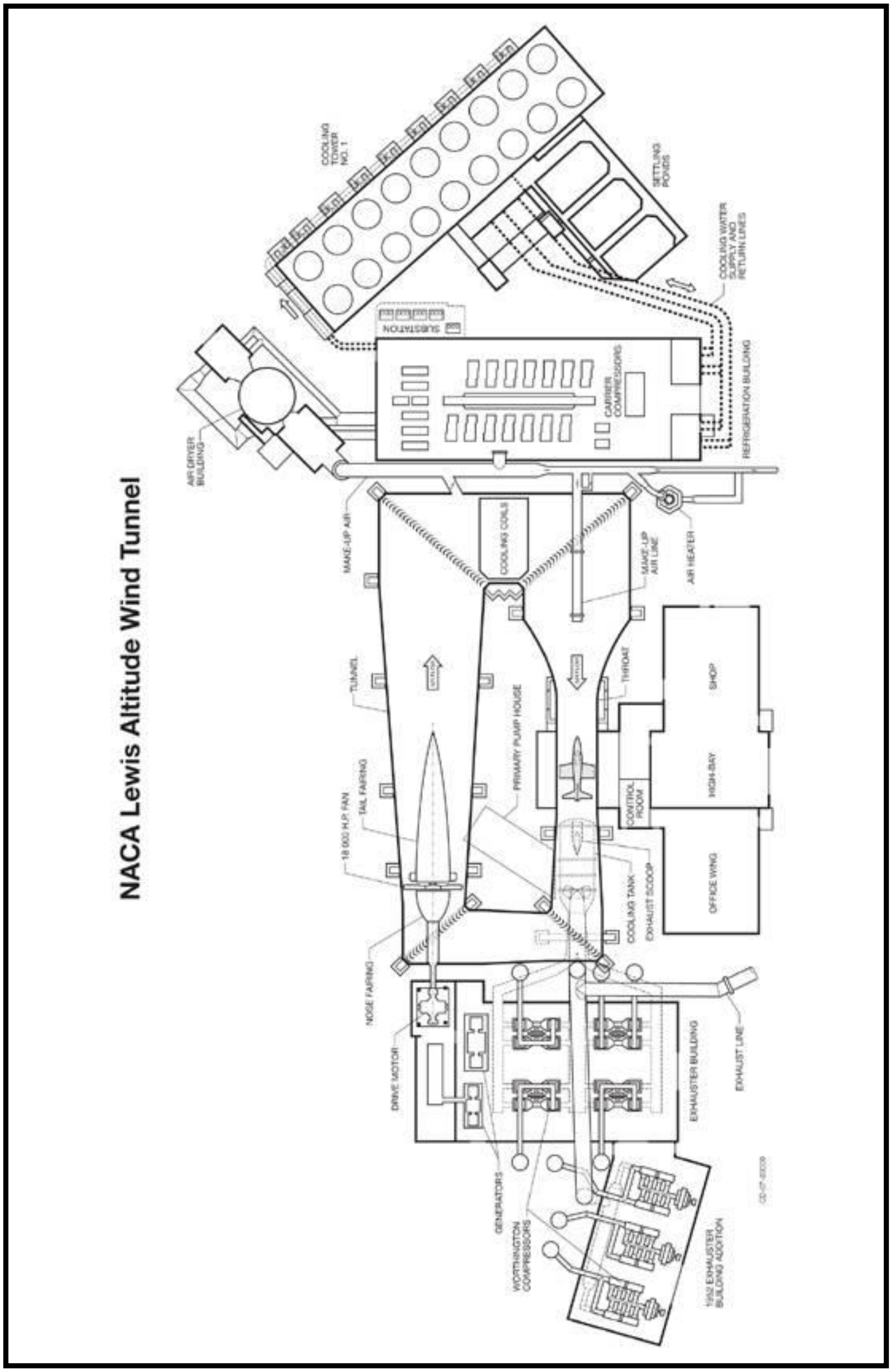
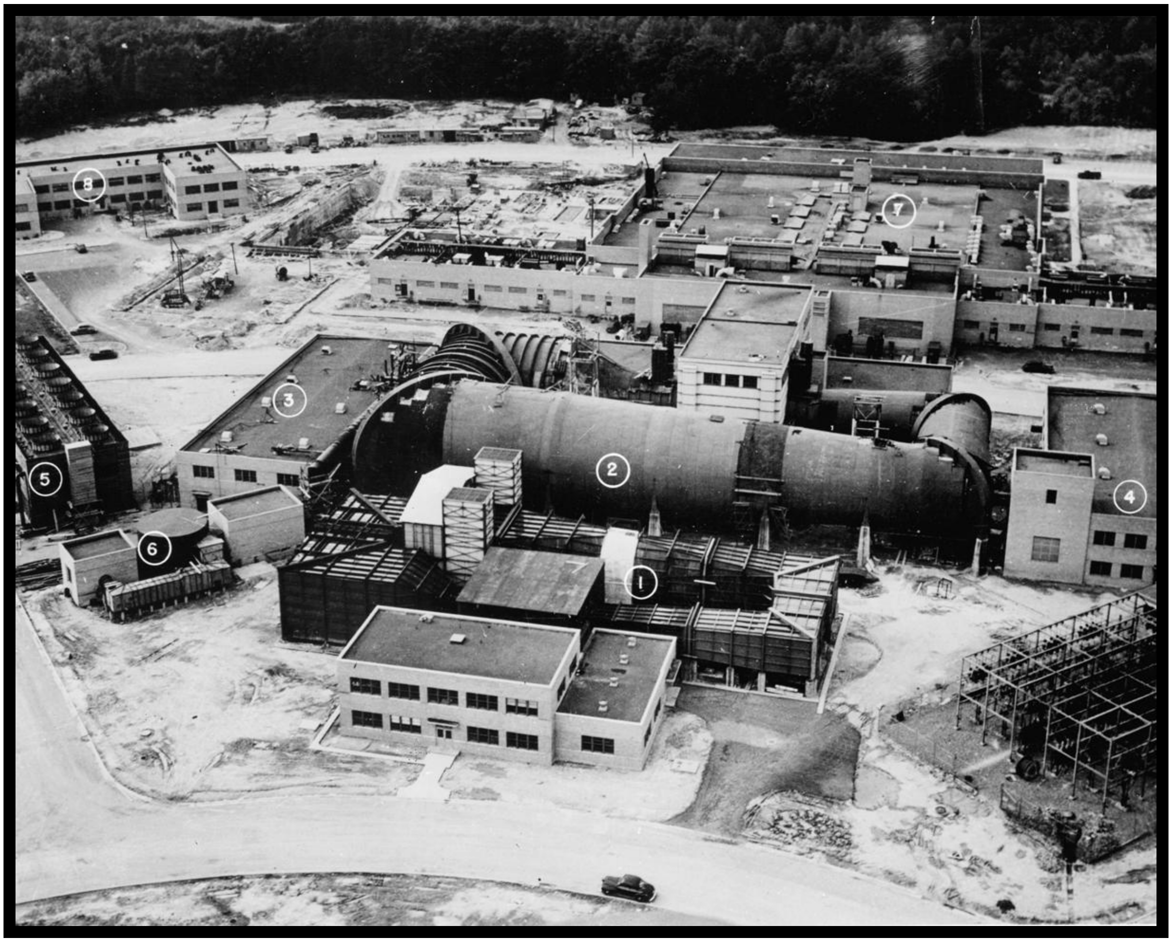


Diagram showing AWT, its internal components, and support buildings
AWT Image No. 6: CD-07-83009a/NASA Glenn Research Center



1) Icing Research Tunnel, 2) Altitude Wind Tunnel, 3) Refrigeration Bldg., 4) Exhauster Bldg., 5)Cooling Tower No.1, 6) Air Dryer Bldg.   AWT Image 7: 1944-05062/NASA Glenn Research Center   (1944)

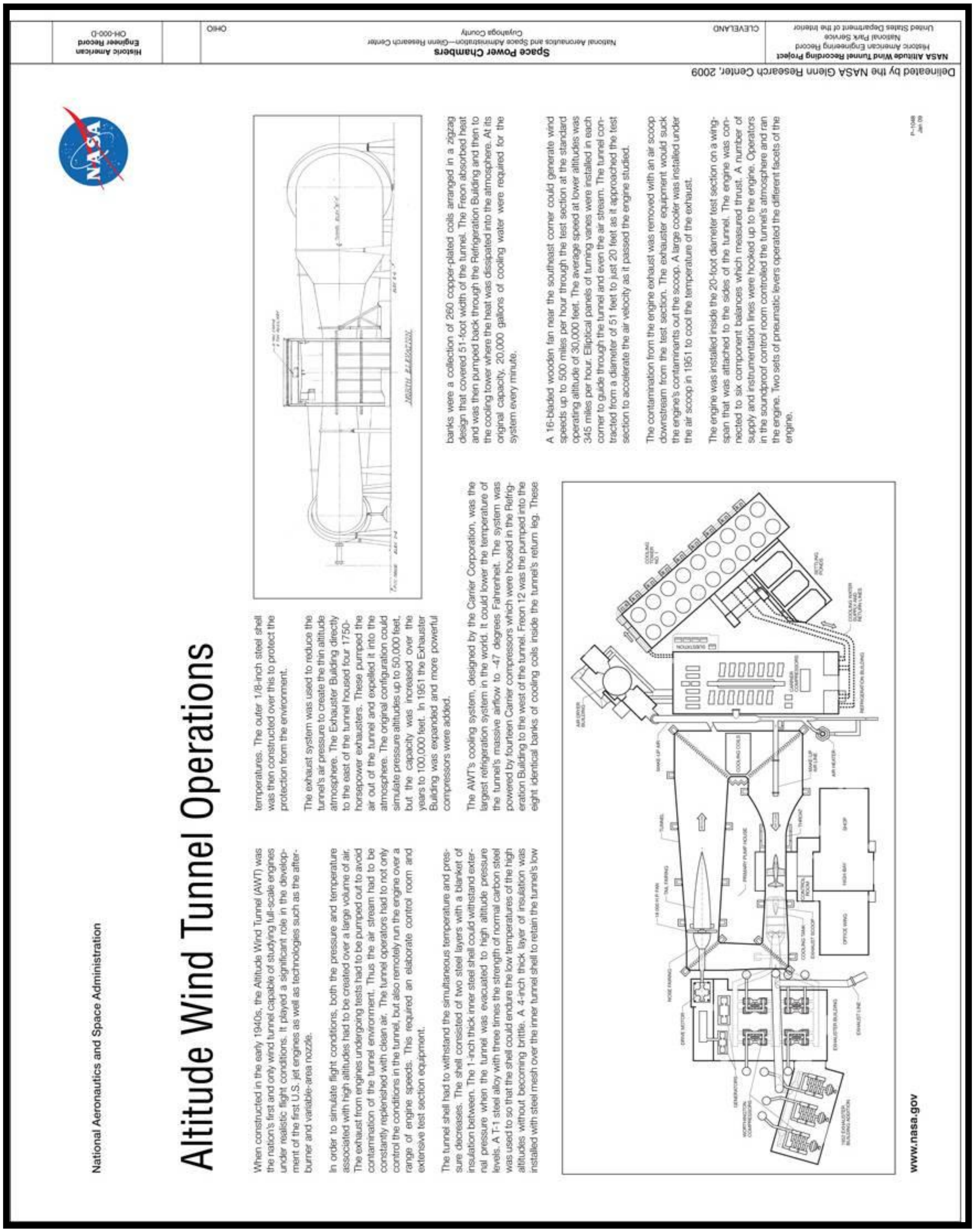
<u>Original Plans:</u> The Altitude Wind Tunnel (AWT) was one of the nation's most sophisticated test facilities when it came online in 1944. The structure was robust enough to sustain the facility as it developed and modified over the next thirty years. Several of the support buildings and infrastructure continue to be utilized by Glenn Research Center.

The basic layout of the Altitude Wind Tunnel was similar to other contemporary wind tunnels, but its altitude simulation and engine firing capabilities required a number of innovations that made the tunnel's design unique. These included the massive refrigeration system, air scoop, composition of the tunnel shell, and exhaust system.

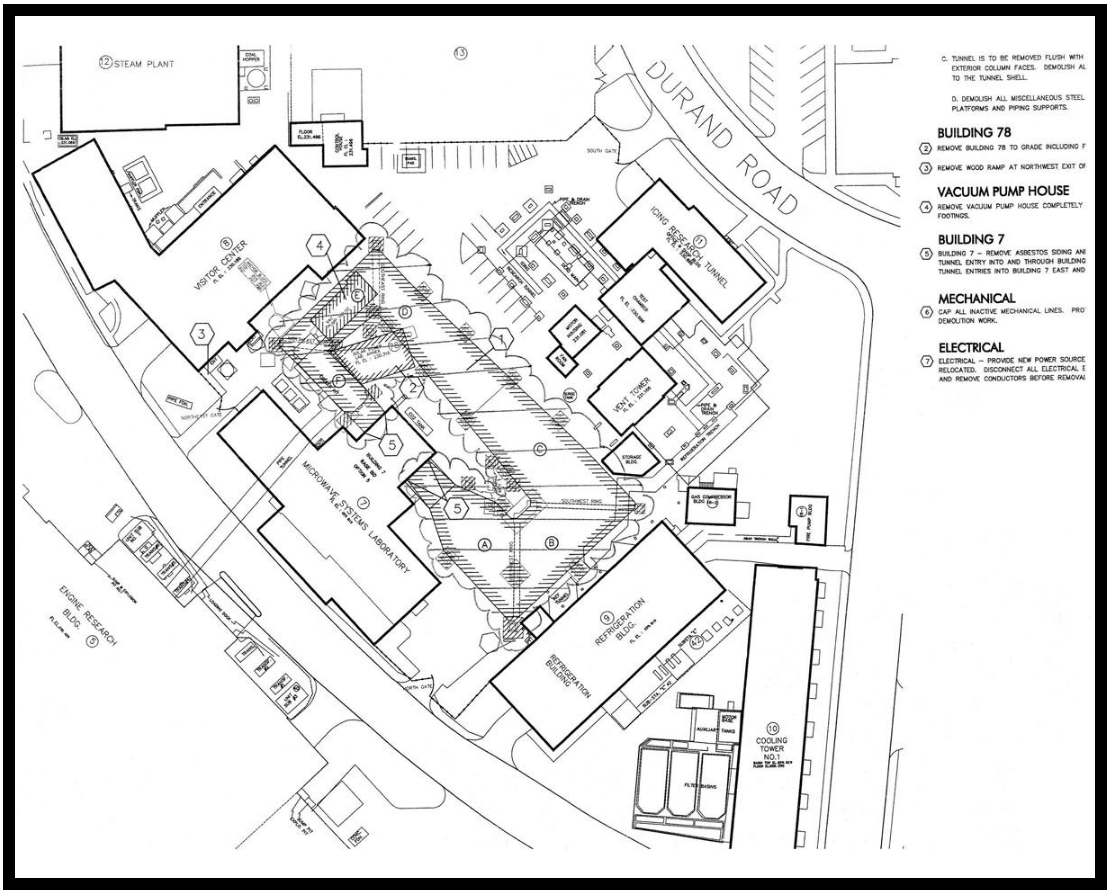
The maximum altitude that could be reproduced in the tunnel—a direct result of the decrease of temperature and air density associated with altitude—was give careful consideration and contributed significantly to the original construction costs. The temperature altitude at which the tunnel was originally designed to operate is 30,000 feet, and the shell was strong enough to simulate pressure altitudes of 50,000 feet. The specific volume of air doubles between 30,000 and 45,000 feet. The maximum speed of the tunnel air stream was 500 miles per hour at 30,000 feet. The maximum air speed decreased at lower altitudes. Its sea level velocity was 345 miles per hour.[2]

The Altitude Wind Tunnel complex consists of several structures. Building 7 (presently the Microwave Systems Laboratory but historically referred to as the Shop and Office Building) is a T-shaped building into the rear of which the tunnel entered from the west and exited to the east. The remainder of the tunnel formed a rectangle immediately behind. The Shop and Office Building originally contained the test chamber and control room in its south extension, two floors of offices in the east wing, a shop area in the west wing, and a high-bay area with an overhead crane running north and south down the middle of the building. The test chamber room in the rear was an open two story space with the tunnel sunken in the floor.

The Exhauster Building (Building 8, currently the Visitors Information Center) is a two-story rectangular structure located immediately to the east of the wind tunnel. The Refrigeration Building (Building 9) is a rectangular structure located to the immediate west of the tunnel. Other related buildings include Cooling Tower No.1 (Building 10), the Steam Plant (Building 12), and the electrical Substation B (Building 13). These buildings were not effected by the demolition. The Vacuum Pump House and the Circulating Water Pump House (Building 78) which were located underneath the tunnel were demolished with the tunnel shell.



AWT Image No. 8: P-1048/NASA Glenn Research Center



Areas of Altitude Wind Tunnel scheduled to be demolished are indicated by hash marks.
AWT Image 9: CF: Drawing no. A-1, Demolition of Building 7 Altitude Wind Tunnel *(2005)*

Project Information: This report was part of a wider effort to document the Altitude Wind Tunnel prior to its demolition. This documentation was formally begun in May 2005 after Statement of Work 6.31 for the NASA Glenn History Program was finalized. The project includes the gathering of records, images, films, oral histories, and researching the facility, its tests, and significance. The resulting information is being disseminated via a book, website, multimedia cd-rom, documentary video, and this three-section construction report.

In 2005, NASA Glenn proposed to remove the entire Altitude Wind Tunnel circuit except for the test section within the high-bay of the Building 7. Building 7 and most of the other support buildings were not included in the demolition. Although the AWT was unique based on its sheer size alone, the maintenance costs for the facility became so high as to be justified only by the largest of research programs. Although mostly idle since the mid-1970s, this facility had a rich history and played an important role in NASA and aerospace history. For this reason NASA Glenn felt it was important to document the facility as thoroughly as possible before its destruction, and share the information with the public and within the agency.

Historians: Bob Arrighi Wyle Information Systems, Inc.
NASA Glenn History Program, Cleveland, OH

A. Physical History

Date of Construction: Excavations for the tunnel foundations began in May 1942 and were completed by late December. Construction of the tunnel began in late 1942 and was completed in January 1944. The frame of the Shop and Office Building was in place by September 1942 and the building was largely built by September 1943. The building's test section and control room were complete in January 1944. The Refrigeration and Exhauster buildings were completed in the fall of 1943. The facility conducted its first test run on February 4, 1944.[3]

Engineers: Alfred Young, Louis Monroe, Larry Marcus, Harold Friedman, Carl Bioletti, Walter Vincenti, John Macomber, Manfred Massa of the National Advisory Committee for Aeronautics.[4] Carrier Air Conditioning Company.

Contractors: Sam W. Emerson Company, Pittsburgh-DesMoines Steel Company, Carrier Air Conditioning Company, Collier, General Electric, York Refrigeration Company, Arthur E. Magher Company.[5]

Owners: The facility was originally constructed as a wind tunnel for the National Advisory Committee for Aeronautics' Aircraft Engine Research Laboratory. The lab's name was changed to the Flight Propulsion Laboratory in April 1947. The name was modified to be the Lewis Flight Propulsion Laboratory in 1948 in honor of the recently deceased George Lewis, the NACA's Director of Aeronautical Research. After the NACA's integration into the new NASA space agency on October 1, 1958, the name was changed once again to the Lewis Research Center. In March 1999, its name transformed again to the John H. Glenn Research Center.

Significance: The Altitude Wind Tunnel (AWT) was the first wind tunnel in the United States, and possibly the world, capable of operating full-scale aircraft engines in conditions that replicated those actually encountered by aircraft during flight. In 1940 the NACA lacked a facility capable of testing modern full-scale engines. At the time it was constructed, the AWT was claimed that the tunnel and its support buildings were the most costly grouping of equipment assembled to test a single engine,[6] the facility required more electricity to operate than the entire city of Columbus, Ohio,[7] and the design required more engineering man-hours than the Boulder Dam.[8]

Although initially constructed to study reciprocating engines during World War II, the AWT's first ten years were spent almost exclusively improving the new technologies associated with turbojet, ramjet, and turboprop engines. Every early turbojet design and many of the second and third generation models were studied in the AWT. These tests included the nation's first jet aircraft, the Bell YP-59A, the Westinghouse 19XB jet engine, the Pratt & Whitney J57. During this period, the tunnel contributed significantly to the improved capabilities of the turbojet through a steady stream of investigations on a number of engines. The AWT also played a primary role in resolving cooling problems for the B-29 bomber's Wright R-3350 engines during the World War II.

In the late-1950s, the facility shifted its focus to space, and the AWT's large interior was used for Project Mercury qualification testing. Then sections of the tunnel were sealed off in 1961 to create two large test chambers and renamed the Space Power Chambers.[a] Although the facility has been mostly dormant since the mid-1970s, it had played a significant role in the progression of the nation's aerospace programs from the World War II reciprocating engine to the first turbojet models to more advanced jets of the 1950s through Project Mercury, the Apollo Program, and Centaur missions.

NACA researcher demonstrating ramjet model with AWT display
AWT Image 10: 1947-18033/NASA Glenn Research Center (1947)

[a] The Space Power Chambers facility is discussed in detail in the Space Power Chambers section of this report

Topography:
The Altitude Wind Tunnel (AWT) was located on a portion of the original two hundred acre areas acquired in late-1940 from the Cleveland Municipal Airport by the National Advisory Committee for Aeronautics (NACA) for an engine research laboratory. The site had previously been used by the airport for parking and grandstands for the annual National Air Races.[9] The airport borders the center on the east. The rest of the area is loosely follows the Rocky River which bows to the northwest around the main campus. The river valley is densely forested, but the main portion of the National Aeronautics and Space Administration (NASA) property is level and treeless.

Parking lot for the National Air Races. Future site of NASA Glenn Research Center.
AWT Image 11: 1991-01875/NASA Glenn Research Center (1930s)

The research center was originally called the Aircraft Engine Research Laboratory. It was the third NACA lab and the only one dedicated to propulsion and engine studies. After the post-World War II emergence of the turbojet, the lab's name was changed to the Flight Propulsion Laboratory in April 1947. The name was modified again in 1948 to the Lewis Flight Propulsion Laboratory in 1948 in honor of the recently deceased George Lewis, the NACA's Director of Aeronautical Research. After the NACA's integration into the new NASA on October 1, 1958, the name was changed once again to the Lewis Research Center. In March 1999, its name transformed again to the John H. Glenn Research Center at Lewis Field.

The Altitude Wind Tunnel is on a flat, featureless area at an elevation ranging from 751 to 759 feet above sea level. The tunnel complex faces north in the wedge-shaped block of Ames, Moffett, Durand, and Taylor roads near the center of the NASA Glenn Research Center at Lewis Field. Other buildings directly related to the Altitude Wind Tunnel are in the immediate vicinity.

The nearby area contains several other laboratory buildings, including the Engine Research Building (Building 5), the Icing Research Tunnel (Building 6), and several small support buildings for the Icing Research Tunnel. The Icing Research Tunnel and Altitude Wind Tunnel were constructed simultaneously and shared much of their support infrastructure. Nearly all these original buildings are of similar design and appearance, which gives the area a unified appearance.

View from northwest of the NACA Lewis main campus with the Rocky River in foreground and Cleveland Municipal Airport behind AWT Image No.12: 1957-44870/NASA Glenn Research Center (1957)

Construction of Altitude Wind Tunnel as it nears completion
AWT Image 13: 1944-04804/NASA Glenn Research Center *(1944)*

Original Construction:
The ground was broken for the National Advisory Committee for Aeronautics' (NACA) Aircraft Engine Research Laboratory (AERL) on January 23, 1941. The Altitude Wind Tunnel (AWT) was a crucial component in the overall design of the new lab and would be one of the most daunting challenges facing the NACA engineers. Although the agency was experienced in aerodynamic wind tunnels, this would be its first attempt at a controlled-atmosphere propulsion wind tunnel.

Design work for the new engine laboratory was well underway at Langley Field by the time of the groundbreaking. Edward Raymond Sharp had spent the previous six months working with Smith deFrance on the rapid construction of the Ames Aeronautical Laboratory in Sunnyvale, California. When the appropriation for the new engine research lab was approved, Sharp was recalled to Langley to oversee the design and construction planning for the new Cleveland lab. After gathering a group from the Langley administrative section, the plans for the engine lab were drawn up in the offices of Langley's Structural Resources Laboratory.

The main design group consisted of approximately thirty engineers and draftsmen, but there were also smaller groups working separately on specific facilities. Among these was a group led by Carl Bioletti at Ames working on the tunnel's distinctive shell and drive system. This faction included Walter Vincenti, John Macomber and Manfred Massa [10]

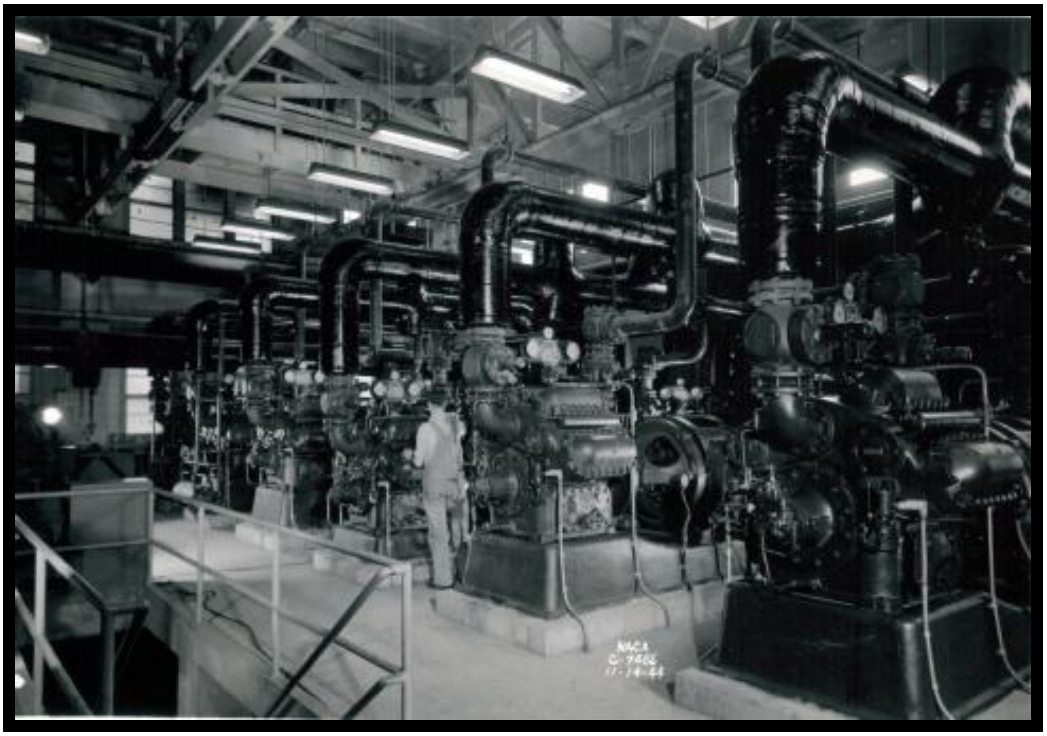
The AWT's ability to simulate altitude with both pressure and temperatures made its design more difficult than the pressure tunnels at Langley and Ames. The simultaneous changes in pressure and temperature resulted in uneven stress loads. Pressure and temperature would decrease within the tunnel more rapidly than on the support rings, resulting in a great deal of stress on the rings. [11]

Walter Vincenti at the Ames lab was unable to find a method to calculate that type thermal stress. Vincenti consulted with Stanford professor, Stephen Timoshenko, a leading expert on structural dynamics. Timoshenko provided his former student with some calculations which resolved the issue. Vincenti sent the calculations and notes to the Cleveland team.[12]

Engineers at Langley, including Al Young and Larry Marcus, designed the Shop and Office Building and other AWT support buildings. The team also planned the tunnel's fan, exhaust and make-up air systems, and air scoop. Young oversaw much of the design and co-wrote the Design and Performance Specifications.[13]

One of the most difficult tasks was designing a system for cooling the massive airflow. After viewing the struggles of the Langley team, Willis Carrier convinced the NACA to forsake their new cooling coil design with its streamlined tubes. After simultaneously testing of the two systems, the Carrier arrangement proved to be superior.

Since the refrigeration system was unique with many previously untried facets, Carrier built a scale model of the tunnel at its plant to facilitate the design. It was determined that the distribution of the coolant in large amounts and at specific pressures resulted in the vaporization of the coolant throughout the entire tube in the cooling coils. The Carrier system required an enormous surface area for its cooling coils, so a zigzag design was developed which increased the coils' surface by four times.[14] The standard Carrier compressors were modified to use Freon-12. [15]



Fourteen Carrier Corporation centrifugal compressors powered the complex refrigeration system
AWT Image No. 14: 1944-7456/NASA Glenn Research Center (1944)

Construction of the Aircraft Engine Research Laboratory near site of Altitude Wind Tunnel
AWT Image No. 15: 1942-01171/NASA Glenn Research Center (1942)

There were still no buildings completed in August 1941 when Ray Sharp arrived from Langley to oversee the construction. He was followed in December by a large contingent of Langley personnel as the United States entered World War II. This new group was managed by Ernest Whitney and Beverly Gulick. The AWT project engineers used Gulick's draftsmen and designers to help design certain aspects of the tunnel.[16]

In a purely ceremonial event, AERL research was formally initiated on May 8, 1942 as an engine was run in the Propeller Research Building for NACA management, local dignitaries, and the media.[17] Just three days later, however, Commanding General of the U. S. Armies, Henry "Hap" Arnold, requested that the NACA's priority rating be elevated to Class D-1 to expedite the construction of the AERL. This was approved by the Bureau of the Budget several days later.[18] Unfortunately, the construction suffered delays and setbacks caused in part by competition with other agencies for war time congressional funding.

George Lewis traveled from Washington every Monday to visit the Cleveland lab and oversee its progress.[19] The design team had moved from Langley to Cleveland, the military provided special supplies, contractors were given new contracts and pressured to meet deadlines, and Congress approved additional funds.[20] In the end, the lab was completed ahead of schedule but at nearly twice the original estimated cost.[21] Construction of the AWT, however, continued to stall and would not be complete for another year.

View from southwest of pylons for the AWT; steel framing for Shop & Office Bldg.
AWT Image 16: 2007-02296/NASA Glenn Research Center *(1942)*

Design of the tunnel's electrical drive and steel structure was scheduled to be completed in February 1942. General Electric oversaw the creation of the tunnel's 18,000 horsepower drive motor. This powered a large 32 foot diameter propeller that was designed and fabricated at Langley. It was shipped to Cleveland on May 28, 1943 and the pieces were assembled in the Hangar. [22]

After winning the contract for the AWT's refrigeration system and coils on March 16, 1942, the Carrier Corporation began an extensive test program. To ensure their performance, Carrier designed many of the valves and pumps specifically for the AWT compressors.[23] Louis Monroe, a former employee of Carrier Corporation, was responsible for bringing the complex refrigeration system online. [24]

Arthur E. Magher Company built the ammonia compressors, Armstrong Cork Company installed the insulating pipe, the Collier Construction Company wired the Carrier equipment, and the York Ice Machine Corporation supplied the exhaust gas coolers, which Norris Brothers installed. The Pittsburgh-Des Moines Steel Company, who constructed much of the tunnel, also installed the cooling coils and headers, liquid and vapor lines, expansion joints, and an exhauster trench.[25] Pittsburgh-Des Moines also installed distribution header, flash cooler pipe, coils, headers, manhole, and electrical ducts. Installation of the Flash Cooler began in mid-June 1943. [26] The Refrigeration Building was 98.55% completed by the end of August 1943. [27]

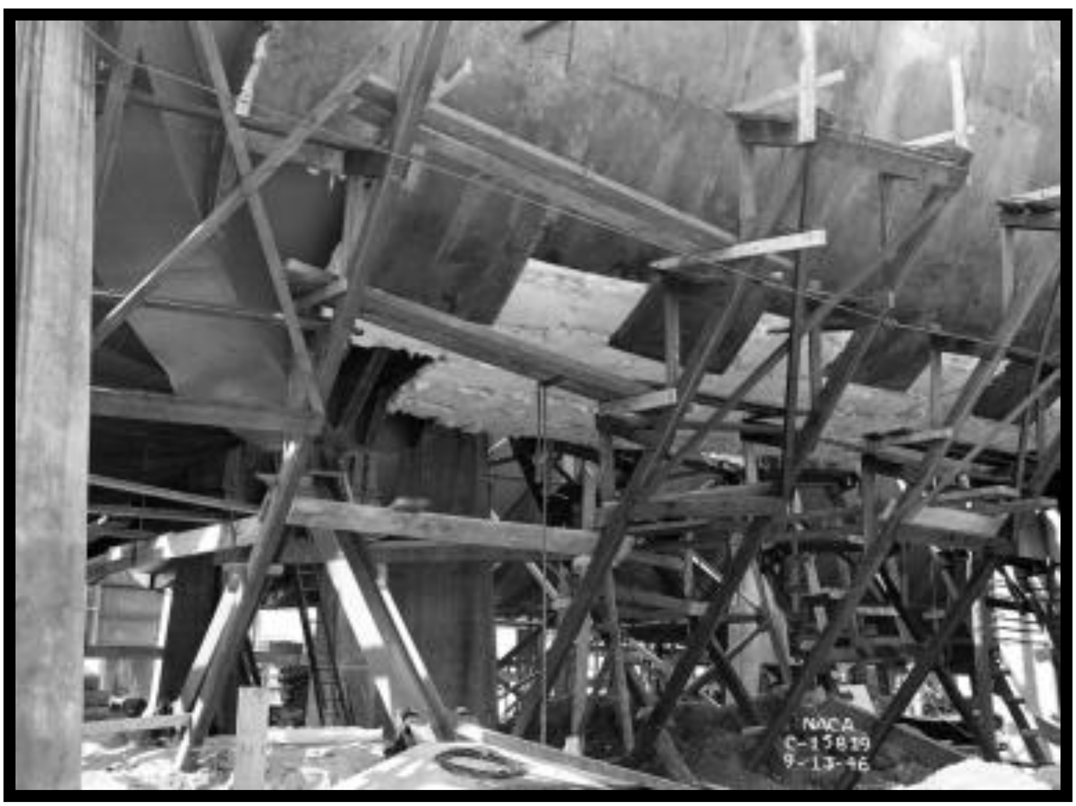
The Sam W. Emerson Company commenced the excavations for the Altitude Wind Tunnel in the spring of 1942 and completed the task by late December. Ray Sharp had negotiated a contract with Emerson to build the AWT Shop and Office Building for $83,000 and install the tunnel's foundation for an additional $95,000.[28]

The Pittsburgh-Des Moines Steel Company constructed most of the actual tunnel, test chamber, and control room.[29] The steel company, which had won many wartime government contracts, also constructed facilities at Los Alamos, battleships, Arnold Engine Development Center's Propulsion Wind Tunnel, and landmarks such as the St. Louis Arch.

Beginning in mid-June with corner A, the turning vanes were installed over the summer of 1943. Each section of vanes took several weeks to erect.[30] The construction of the Office and Shop Building and Exhauster Building were completed in September 1943. This was followed closely by the completion of Refrigeration Building.[31]

Erection of Altitude Wind Tunnel corner ring in January 1943.
AWT Image No. 17: 1944-06707/NASA Glenn Research Center *(1943)*

View from south of erection of the Altitude Wind Tunnel's shell in September 1943l
AWT Image 18: 1946-15817/NASA Glenn Research Center (1943)



Application of fiberglass insulation and protective plate covering to the right of girder A
AWT Image 19: 1946-15819/NASA Glenn Research Center (1943)

View from west of construction of south leg of AWT. Fan drive shaft is at far end.
AWT Image No.20: 1944-07410/NASA Glenn Research Center *(1944)*

Assembly of 32-foot diameter spruce wood fan in the Hangar prior to its installation in AWT
AWT Image No. 21: 1943-01848/NASA Glenn Research Center (1943)

In the final months of construction, Harold Friedman was asked to design a system to subject the propellant for the test articles to simulated altitude conditions prior to its introduction into the engines. Friedman, just a couple years out of university, was given no real guidance on fuel behavior or how to design the system. The system he created used a vacuum tank to condition the fuel to the proper altitude. The facility began operations before the fuel system was finished and it was not implemented.[32]

Robert M. Pelkey, Inc. was hired on July 20, 1944 to complete the painting of the AWT, Icing Tunnel, and test chamber. The control room, test section, and tunnel were completed in January 1944. [33] The first test was run on February 1, 1944. Willis Carrier and a team of engineers were on hand for the first run of the tunnel to ensure there were no malfunctions.

Alterations:
The Altitude Wind Tunnel underwent a series of alterations throughout its 30 year operating period. These included exhaust system improvements, the additional of small subsidiary tunnels, removal of internal components, and conversion into a vacuum tank facility.

Because of the arrangement made with electric company, the Altitude Wind Tunnel (AWT) initially ran only during the night. Without the huge power loads of the refrigeration and drive systems, Chief of the Engine Installation Division, Abe Silverstein, configured the exhausters and air dryer to run a new small supersonic tunnel during the day.[b] It was the first of three small tunnels built vertically atop one another and housed in the three-story Small Supersonic Tunnel Building between the AWT and the Icing Research Tunnel. These three small open circuit tunnels were known as the Stack Tunnels. The first, capable of Mach 1.91, was built in just ninety days and was operating by August 1945.[34] Mach 3.96 and Mach 3.05 tunnels were added in the 1949 and 1951 respectively. The tunnels were used to study the effects of boundary layer and inlets for jet engines.[35]

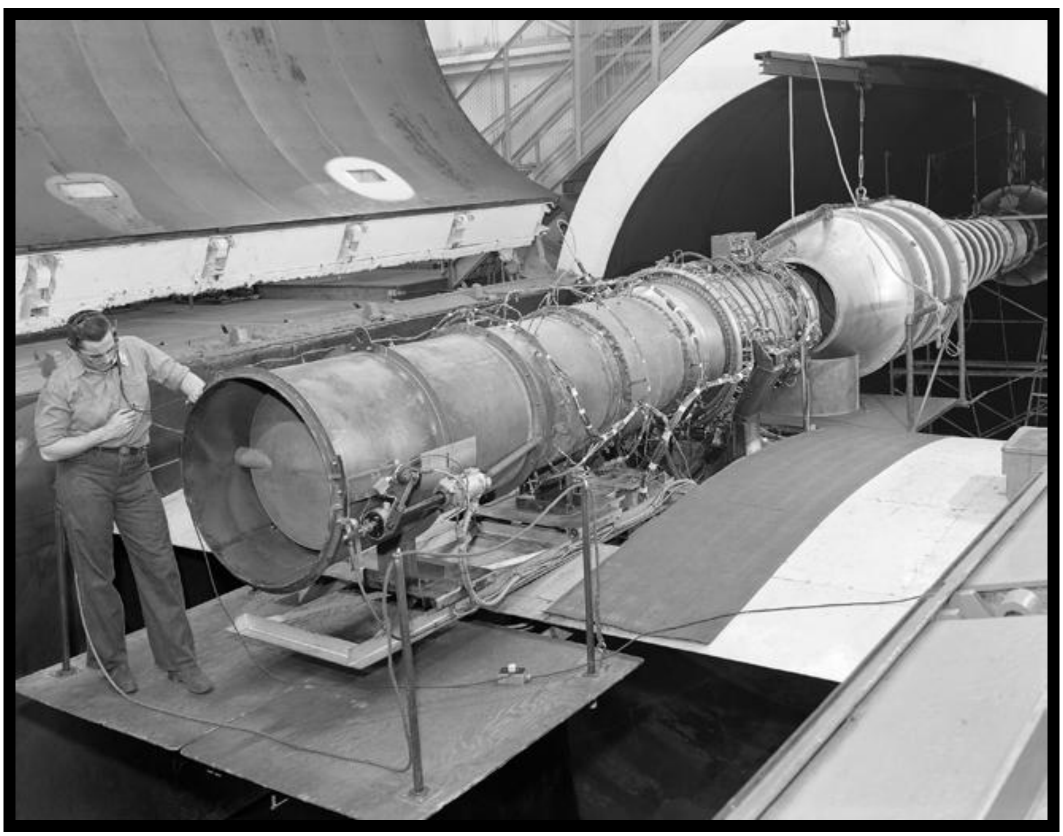
View of Small Supersonic Tunnel Building off southwest corner of the AWT
Image No. 22: 1945-13046/NASA Glenn Research Center (1945)

[b] More detailed description of the Small Supersonic Tunnel Building available in the Support Buildings section.

In the basement of the AWT's Shop and Office Building is a small 4 by 10-inch supersonic wind tunnel referred to as the Duct Lab.[c] Like the Stack Tunnels, it utilized the AWT's exhausters for small scale flow physics studies. The Duct Lab was operating by November 1945. Despite the fact that the AWT has not operated in decades, the Duct Lab has continued to be used through 2006.

In response to complaints received immediately after the cessation of World War II, baffles were added to the Exhauster Building vent pipes to minimize low-frequency vibrations and noise. The tunnel's reciprocating exhausters tended to rattle windows and doors over seven miles away. The near daily noise was considered almost unbearable by some residents.[36] Over a period of several weeks in October 1945, at a cost of $20,000, the lab installed eight mufflers manufactured by Maxim Silencer.[37] [38]

Aircraft speeds increased rapidly in the 1940s with the advent of the jet engine. The AWT's 500 mile per hour air speed capacity was no longer sufficient to study modern engines. Engineers were able to use ambient pressure outside the AWT's test section in addition to the simulated pressure directly connected to the engine's inlet to increase airflow to over Mach 1. The trade-off was that the effective size of the test section was reduced in size so that it could no longer accommodate full aircraft, but just the engine.[39]



View of test section with a direct-connect air pipe
AWT Image 23: 1955-38288/NASA Glenn Research Center *(1955)*

[c] For additional information on the Duct Lab see the Support Buildings section of this paper.

From May through December 1951, a number of modifications were made to modernize the AWT for the newer, more powerful jet engines. A permanent metal deck was installed across the test section so to provide technicians with a steady platform on which to work on the engines. The largest upgrade was the addition of a smaller rectangular annex with new compressors to the northeast corner of the Exhauster Building.[d] An exhaust gas cooler, pump house, and cooler pit were installed underneath the northeast segment of the tunnel. Additional cells were added to the western end of the cooling tower at this time, as well.[40]

Installation of new exhaust gas cooler underneath northeast section of the AWT
AWT Image No. 24: 2007-02590/NASA Glenn Research Center (1951)

A $120,000 air-expansion refrigeration turbine added to the Make-up Air System in 1953 increased the tunnel's cooling capabilities to -100° F. Engine compressor at high corrected speeds and high-altitude turbojet starting could then be studied.[41]

A new fuel supply system was installed for the J-40-10 afterburner tests in 1953. This included a new 4-inch diameter fuel line that ran from the Exhauster Building to the fuel conditioning room to the east of the Shop and Office Building's test chamber.[42]

In 1957 the Central Air and Exhauster Building, which began operating in 1952 with the new Propulsion System Laboratory, was linked to the AWT's exhaust system. The AWT had already been connected to the Engine Research Building's exhausters, so now there were three air supply systems to complement each other. These three systems combined to close a longstanding gap between the lab's airflow capacity and the test facilities' needs.[43]

[d] For additional information on the new Exhauster Building and pump house see the Support Buildings section of this paper

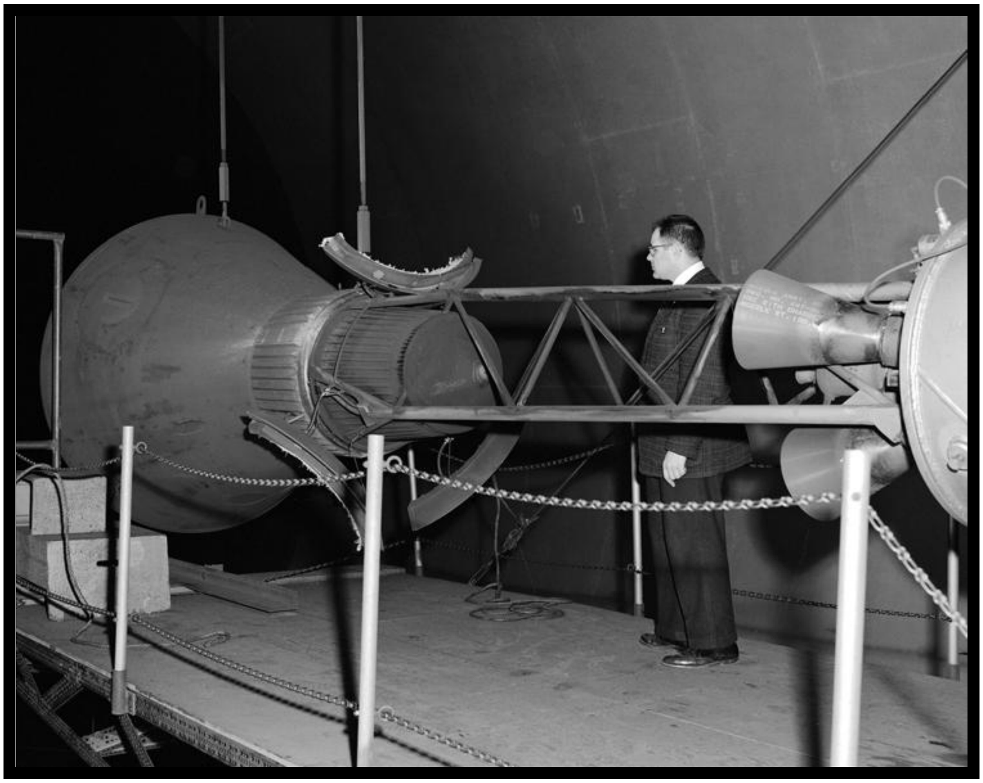
The 6-foot diameter pipe entered the top of the tunnel's northeast corner. The Garlock Packing Company created and installed the elliptical –shaped rubber expansion joint.[44] The result for the AWT was an improvement from 12 to 7 pounds/second at 50,000 feet and 66 to 51 at 28,000 feet.[45]

Erection of pipe connecting the lab's new test facilities to the AWT and Engine Research Bldg's exhausters
AWT Image No.25: 2007-02555/NASA Glenn Research Center (1957)

In 1958 the AWT ceased to be utilized as a wind tunnel and was instead used for its altitude simulation capabilities and large interior space. The tunnel shut down from January to May 1958 for a leak test. By early 1959, the turning vanes, coiling coils, and Make-Up Air lines were removed from the western end of the tunnel. This area was used for a series of Project Mercury tests that did not require an air stream.

In 1961, bulkheads were inserted in the tunnel to create two large test chambers and the drive fan, exhaust scoop, and remaining turning vanes were removed. On September 12, 1962 it was named the Space Power Chambers.[e]

[e] For additional information on this process see the Space Power Chamber section of this paper.

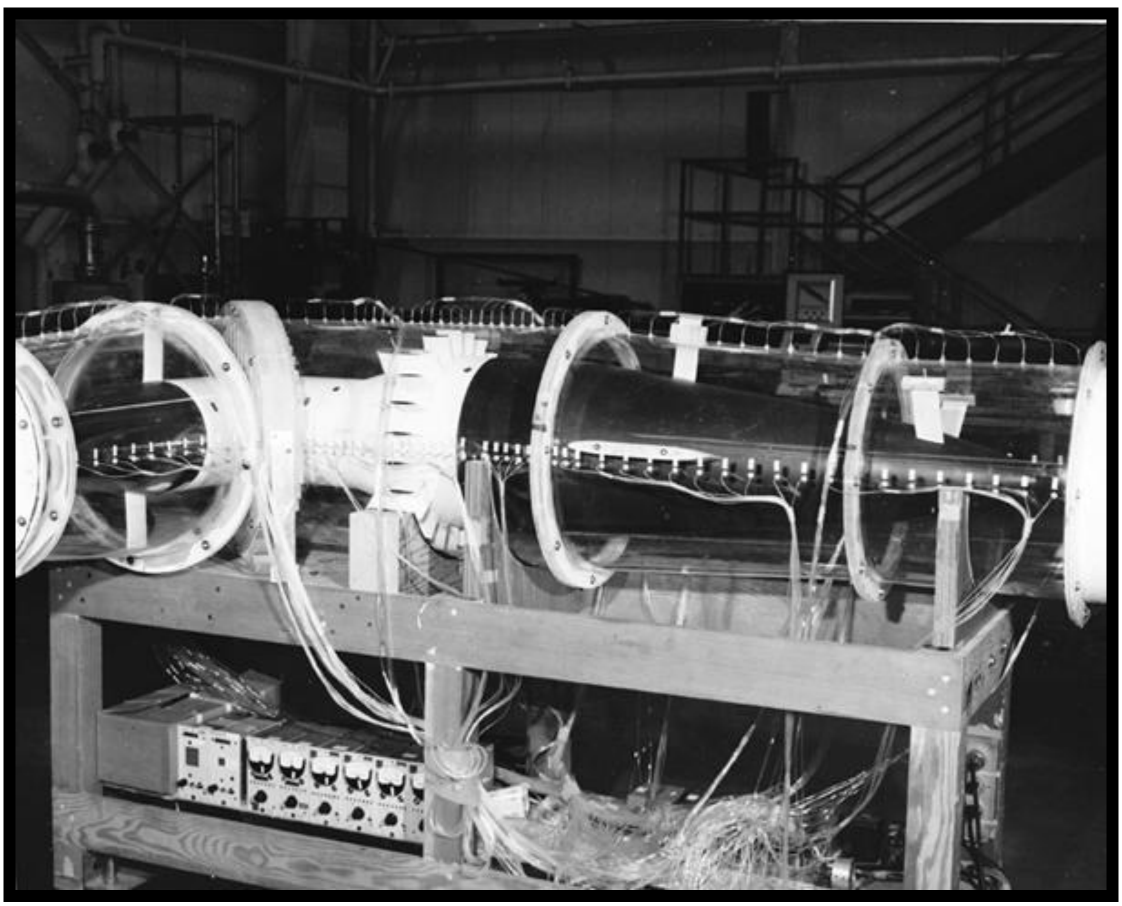


Project Mercury escape tower test near southwest corner of the Altitude Wind Tunnel.
AWT Image No.26: 1960-53281/NASA Glenn Research Center (1960)

31-foot diameter bulkhead in southeast corner of AWT to create the Space Power Chamber
AWT Image No.27: 1962-60343/NASA Glenn Research Center (1962)

In 1981 the Sverdrup Corporation was contracted to conduct an extensive Preliminary Engineering Report to explore the costs and options for remodeling the Space Power Chambers for use once again as a wind tunnel for icing and V/STOL testing. Sverdrup delivered cost estimates and a feasibility study for future use of existing AWT structures. It was determined that the existing infrastructure was robust enough to be the basis for the new tunnel.[46] An AWT Project Office was established to oversee the proposed tunnel rehabilitation. Since the tunnel's internal elements had been removed during the creation of the Space Power Chamber, a new test section, heat exchanger, two-stage fan system, exhaust scoop, and four turning vanes would have to be installed.[47]

A Congressional Advisory Committee on Aeronautics Assessment cancelled the rehabilitation in March 1985. The AWT Project had consumed a substantial amount of personnel and financial resources, and it appeared that the actual rehabilitation of the tunnel would exceed the $160 million already proposed. The committee also questioned the AWT's predicted capabilities and suggested that the research needs could be met by existing wind tunnels.[48]



Model built to study proposed rehabilitation of the Altitude Wind Tunnel in the early 1980s
AWT Image No.28: 1984-00784/NASA Glenn Research Center *(1984)*

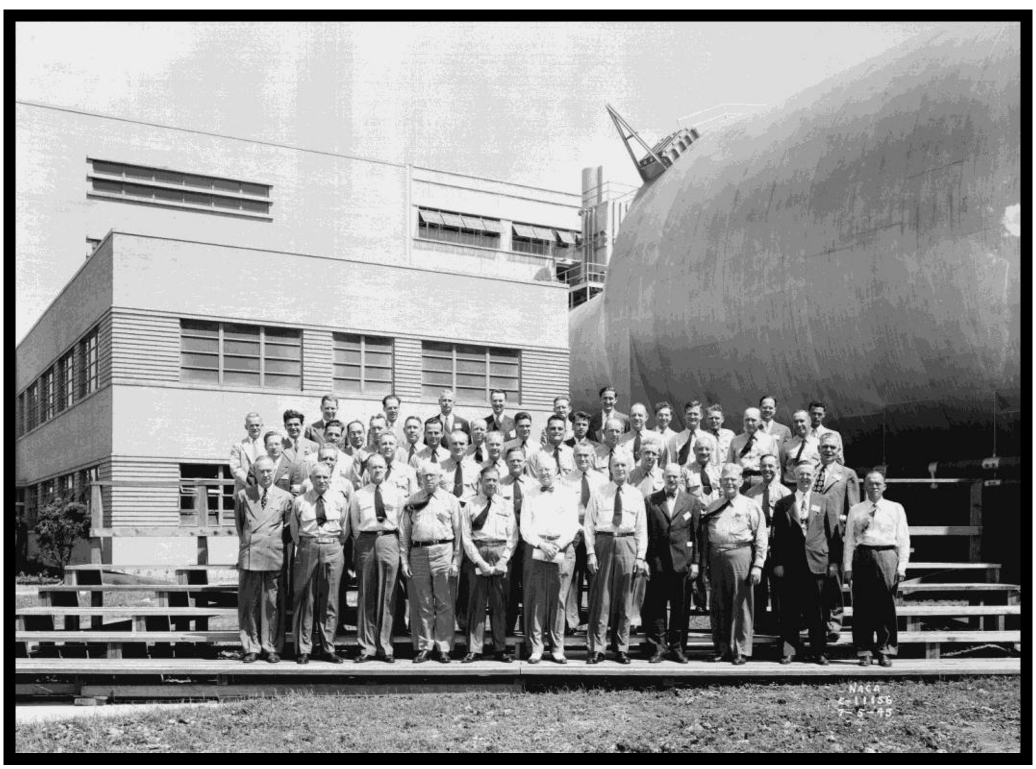
B. Events History

World War II: Less than twenty years after World War I, the United States was once again facing a European war and superior German aircraft. NACA's Director of Aeronautics, George Lewis's, report describing his 1936 trip to Germany was the first intimation that the NACA's Langley Laboratory might be inadequate for the nation's future research needs.

At the time, Langley, with its four hundred employees, was the NACA's only research lab. It is estimated that Germany had 7500 aeronautical researchers.[49] In addition, the NACA had concentrated its research almost exclusively on aerodynamics with only cursory propulsion work. Those at Langley who were working on aircraft engines primarily studied single cylinders and extrapolated the test data for full-scale engines. This technique could produce misleading data.[50]

As the second World War approached, it was evident that aircraft would be as important as navies or ground troops. Although aircraft manufactured in the United States were numerous, they slower and incapable of the altitudes that the Germans achieved. At the outset of the World War II, US aircraft engines were neither diesel nor liquid-cooled.[51]

In response to Lewis's report, the NACA set up a special committee under General Oscar Westover, then Chief of the Army Air Corps. It took three years for the committee to address the question of the relation of the NACA to defense of the United States in the event of war, but in 1939 Congress approved funding for the expansion of the NACA. [52]

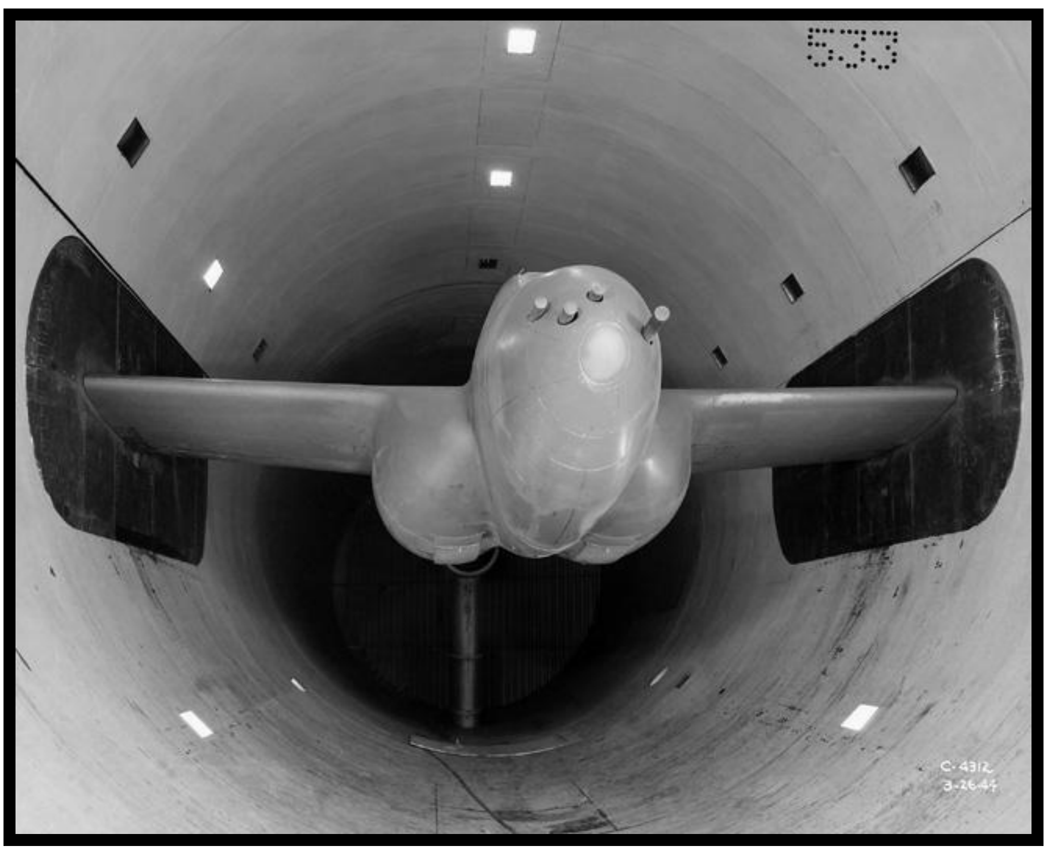


The AWT was the centerpiece of the new laboratory. Stands were erected for visitors publicity photos.
AWT Image No. 29: 1945-11156/NASA Glenn Research Center (1945)

The NACA made the decision to create two new research labs—Ames Aeronautical Laboratory and the Aircraft Engine Research Laboratory (AERL). Ames, at Moffett Field California, was designed to investigate high-speed flight. The AERL, in Cleveland, Ohio, was created to study aircraft propulsion systems, with the unique capability of testing full-scale engines in simulated altitude conditions. George Lewis said "I feel confident today in saying that this new aircraft engine research laboratory will be the Mecca for all the world's aircraft engineers and research workers."[53]

The centerpiece for the new engine lab would be the Altitude Wind Tunnel (AWT), which would be the nation's first wind tunnel capable of studying engine behavior in altitude conditions. Previously there was no way of testing an engine under these conditions except with risky and time consuming flight tests. The AWT was designed to fill this void. Power, speed, drag, vibration, and cooling could all be analyzed in controlled conditions making AWT the most complete facility for testing of full-scale engines prior to production. This ability to test full-size engines instead of just a single cylinder resulted in a more rapid transition from design to flight testing.[54]

Carlton Kemper predicted in March 1944 that, "AERL is unique in having the only altitude wind tunnel in the world. We can expect that this one research tool will give answers to the military services that will more than offset the cost of the laboratory."[55]



The Bell YP-59A Airacomet installed in the Altitude Wind Tunnel test section
AWT Image No. 30: 1944-04312/NASA Glenn Research Center (1944)

One of the most pressing military problems was the overheating of the Wright R-3350 engines that were used to power the new B-29 Superfortress. The B-29 was designed by Boeing specifically for its mission to drop an atomic bomb on Japan.[56] The bomber was the most sophisticated aircraft of its era, but the state-of-the-art R-3350s burned up regularly at the high altitudes the bomber was designed to fly at.[57]

Even though there was tremendous pressure to complete construction of the AWT in order to analyze these R-3350 cooling issues, the first test in the new tunnel was the new Bell XP-59A Airacomet jet. The Airacomet was the first U.S. aircraft to incorporate a turbojet engine. The AWT tests led to a 25% improvement the aircraft's General Electric I-16 engine performance by redesigning the inlets to allow better distribution of airflow.[58] Despite these enhancements, the XP-59A remained too problematic to be used for combat in World War II, and the design was eventually forsaken.[59]

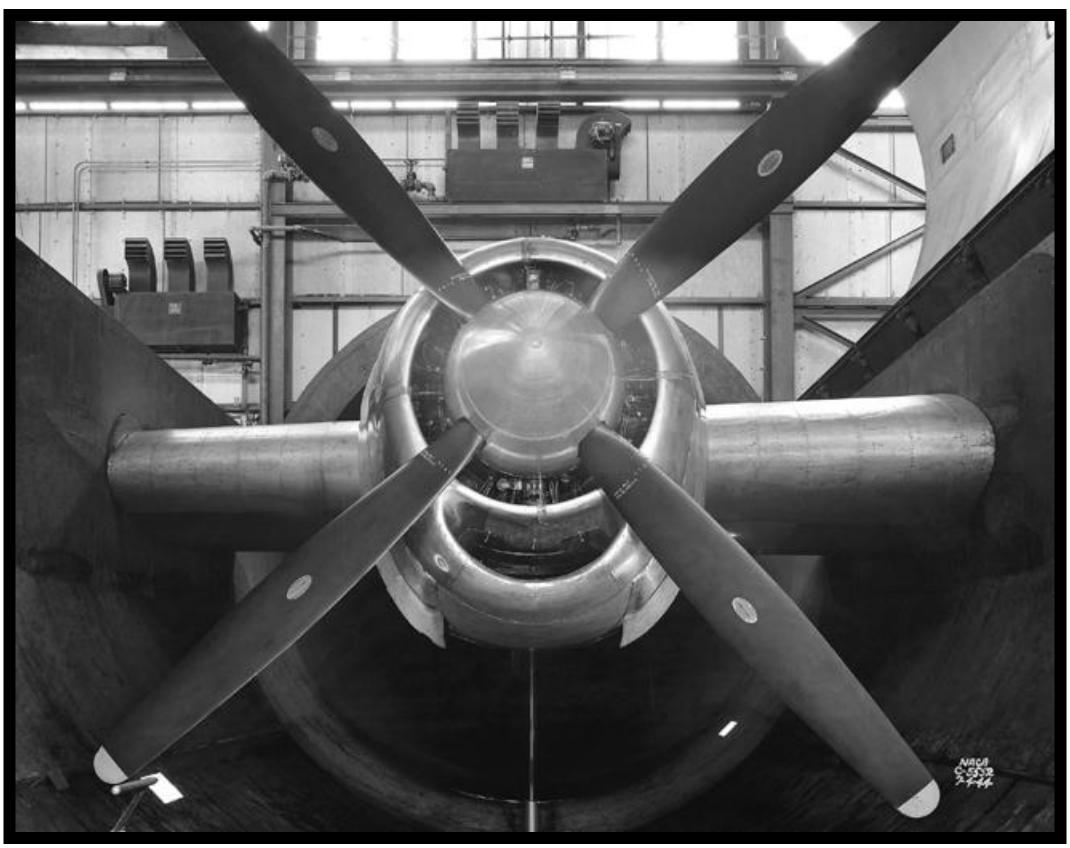
Because of the agreement with the Cleveland electric company, the tunnel operated overnight. During the war, AWT employees were divided into four groups working two shifts, 3PM to 1:30AM and 11PM to 7AM.[60] Generally the first and second shifts set up the broke down and set up the tests, and the third shift ran the tests. Engineers would often have to work all day, then operate the tunnel and test the engine overnight.

The Altitude Wind Tunnel was often run at night due to its massive power loads.
AWT Image No.31: 1944-09514/NASA Glenn Research Center (1944)

The AWT and the Icing Research Tunnel (IRT) at the AERL were used more frequently for military research during World War II than those at Langley or Ames. A study of NACA wind tunnel testing from January 1939 to June 1945 showed that 92.6% of the AWT and IRT's operating time was used for Army and Navy studies. This was compared to 57% at Langley and 56.5% at Ames.[61]

The AWT's most successful wartime study was the resolution of the B-29 cooling issues. The problem stemmed from poor cooling air circulation and irregular fuel mixtures.[62] The massive R-3350s were not allowing enough airflow to reduce the extreme exhaust heat. In addition, the fuel was injected before the supercharger which resulted in the uneven distribution of fuel. AERL researchers developed a copper tube with nozzles was placed around the engine. They were able to measure the temperature of each cylinder and determine which ones which were not receiving the proper amount of fuel. Small amounts of fuel were then sprayed into the cylinders of the nozzles which had not received enough fuel.[63]

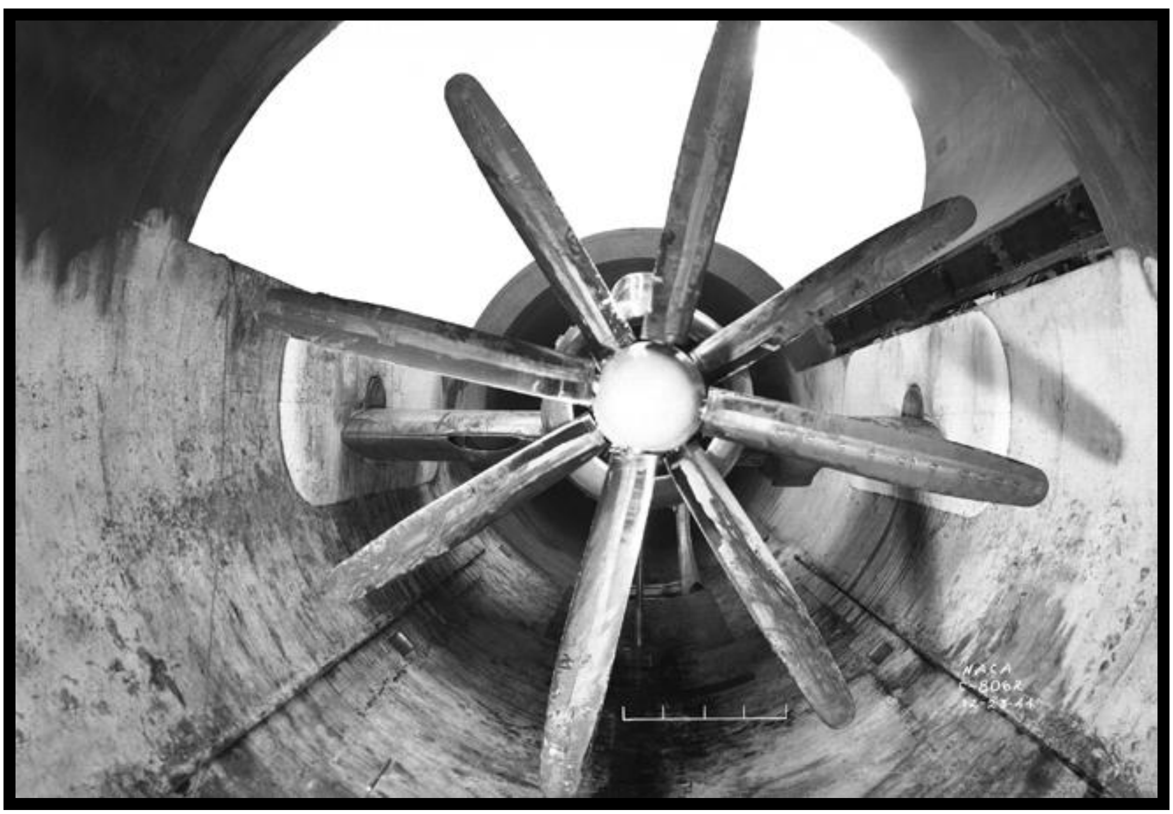
The AERL also studied the R-3350's cowl inlets, particularly the flap design. Using a right inboard nacelle with its 18-cylinder engine and wing section, a wide range of cowl flap configurations were examined in the AWT to study the cooling air pressure drop and distribution, and drag. It was found that sliding flaps required 60 to 80 less horsepower than the original chord flaps.[64]



B-29 bomber's Wright R-3350 installed in the Altitude Wind Tunnel test section
AWT Image No.32: 1944-05552/NASA Glenn Research Center (1944)

The AERL researchers were also able to broaden the B-29s flight range and increase its armament capabilities by increasing the fuel efficiency by 18%.[65] Flight testing afterwards revealed that the modifications resulted in specific range improvements of up to 38%. This improvement translated into a 10,000-foot increase in altitude or gross-weight increase of 10,000 pounds at sea level or 35,000 pounds above 10,000 feet.[66]

Despite the NACA's stated wartime mission to study only existing aircraft types, only one other of AWT's eight wartime tests was on a piston engine, the experimental XTB2D-1 Skypirate torpedo bomber. The Skypirate's R-4360 Wasp Major was the largest reciprocating engine to be mass-produced in the United States at the time. The R-4360 radial engine used two contra-rotating propellers to produce 3,500 pounds of horsepower.[67] Early developmental problems included piston ring sticking and over-cooling of the piston assemblies.[68] Beginning in mid-November 1944, the R-4360 engine was tested in the AWT for a little over a month. The Skypirate was too large to be used on pre-Midway carriers, and the concept of multi-seat torpedo bombers was falling from the military's favor by the time the Midway carriers were put into action in late 1945. It would have been the largest aircraft carrier aircraft of its time had the program gone forward.[69]



Douglas XTB2D-1 Skypirate with its Pratt & Whitney R-4360 engine in the AWT
AWT Image No.33: 1944-08062/NASA Glenn Research Center (1944)

Development of the Turbojet**:** Despite its promise, many in the United States and NACA thought the gas turbine engine was not a viable alternative to the well-developed reciprocating engine. It was believed that the weight of the turbine's components would exceed the aircraft's capabilities and require too much fuel.[70] Although, this was initially a realistic assessment, as the turbojet was perfected during the 1940s and 1950s, these obstacles were overcome. Its speed, ability to use a wide variety of fuels, and the eradication of the reciprocating engine's propeller made the turbojet even more appealing.[71]

In Great Britain Frank Whittle had patented his idea for a gas turbine engine in 1930 and by 1934 had run successful static tests. Unaware of Whittle's engine and working independently in Germany, Hans von Ohain patented his own turbojet design in 1934. Soon afterward, von Ohain began collaborating with Ernst Heinkel to integrate the new engine into a working aircraft. On August 27, 1939 the Heinkel He178 became the first jet aircraft successfully flown.

Upon assuming control of the US Air Corps in 1938, General Henry Arnold called a meeting to identify vital research and development areas for the Air Corps. One of the items on the table was the jet-assisted take-off (JATO). Both Jerome Hunsaker and Vannevar Bush revealed the NACA's closed-mindedness at the time by openly derided the proposal.[72] Abe Silverstein later explained that the NACA was still primarily an aerodynamics-based agency at the time and that "nobody was really looking ahead."[73]

In the meantime, the Europeans were beginning to fly turbojets successfully. By 1940 the Italians developed its own variation of the jet engine, in early 1941 the first rocket-propelled aircraft was flown in Germany, and on May 15, 1941 the British flew their first jet aircraft, the Gloster E.28/39. The first substantive development with the turbojet occurred on July 19, 1942 when the German Messerschmitt Me-262 Schwalbe became the world's first operational fighter jet. The Me-262, which incorporated two 700-horsepower Junkers Juno 004 jet engines, could fly at 540 miles per hour. In addition, the concept of swept wings, below-the-wing nacelles, cannons in the nose, and wing slots were all initiated on the Me-262.[74]

Although the Americans had decided to fight World War II with existing piston aircraft, it was obvious that jets were the future of aeronautics. In March, the NACA called Dr. William Durand out of retirement to head a Special Committee on Jet Propulsion to study the Whittle engine design.[75] This would lead to the July 1942 successful ground testing of the NACA Jeep gas turbine engine at Langley. The Jeep was developed independently of the Whittle engine and was based on an axial-flow design that was limited. After a failued test for NACA committee members the program was put on hold permanently March 1943.[76]

General Arnold had visited Britain in April 1941 to watch the first flight of the Gloucester E-28/39. Through the Lend-Lease agreement, plans for the Whittle engine were secretly brought to the States so that American engineers could duplicate it.[77] A General Electric group in West Lynn, Massachusetts was selected to replicate Whittle's W-1B engine. The result was the 1250-pound thrust GE I-A centrifugal flow engine.[78] On October 3, 1941 Bell Aircraft Corp. was given the task to construct an aircraft which would incorporate the I-A engines. This aircraft, the XP-59A Airacomet, used two of the jet engines mounted under the wings and adjacent to the fuselage.[79]

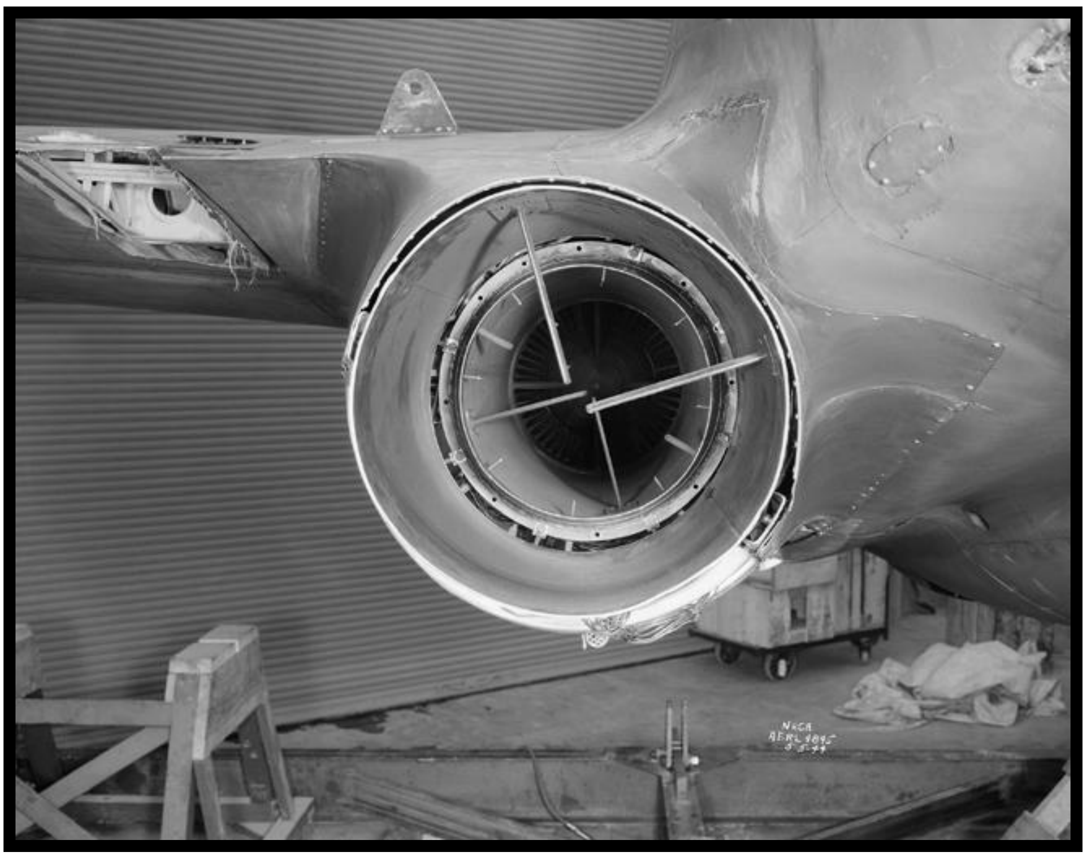
Although it flew, it did not perform well and provided little performance enhancement over the gas turbine version.[80] By July 1943, General Electric (GE) had created an updated version of the I-A engine, which was called the I-16 or J-31. The 1650-pound I-16 was more powerful, but its additional weight prevented the XP-59A from performing any better than with the I-A.[81]

In the fall of 1943, the GE I-16 engine was secretly brought to the NACA's AERL for testing in the newly completed Jet Static Test Laboratory. The I-16 tests were under 24 -our guard and disguised as a "Supercharger Project."[82] NACA and GE researchers were able to improve upon the initial Whittle design.[83]

Raymond Sharp (l) and Abe Silverstein (r) study jet aircraft model
AWT Image No. 34: GPN-2000-001823 (1951)

Eight additional Airacomets were produced during 1943 and test flown at various locations, including Muroc Field. Problems still remained, though, particularly in regards to uneven airflow through its intakes. Abe Silverstein flew to the GE plant to examine the engine and vowed to get it running.[84]

A XP-59A Bell aircraft was brought to Cleveland and the wing tips and tail were cut off so the entire fuselage and engine fit into the AWT's test section. It was tested daily by three shifts from February 4 to May 13, 1944.[85] AERL researchers were able to redesign the inlets allowing better distribution of airflow. This improved the aircraft's performance by 25%.[86] Its I-16 engine was also tested separately at the AERL without the aircraft. Despite the enhancements made in the AWT, the XP-59A remained too problematic to be used for combat in World War II, and the design was forsaken.[87]



General Electric I-16 engine mounted on Bell Airacomet aircraft
AWT Image No.35: 1944-04845/NASA Glenn Research Center *(1944)*

The AWT returned to turbojets after the mid-1944 B-29 studies. The Westinghouse 19B and 19XB engines were tested in fall 1944, and the General Electric TG-180, Lockheed YP-80A and TP80S, and a 20-inch diameter ramjet were all studied in 1945. These early tests produced the first operational afterburners.

On October 22, 1942 Westinghouse Electric had become the first company to begin work on an American-design turbojet engine. They were contracted to build two build to 19A axial-flow turbojet engines. Westinghouse had successfully built a 19A engine by March 1943, and concluded a 100-hour endurance test on July 5. The 19A led directly to several other jet engines, including the 19B. [88]

Beginning in September 1944, the Westinghouse 19B was tested for two months in the AERL's Altitude Wind Tunnel. The test's focused on the operation of the 19B's new designs, the 19B-2 and 19B-8 prototypes, along with experimental prototypes, the 19XB-1 and 19XB-2B. General performances studies were conducted. Fuel nozzles were modified and the combustion chamber set-up was altered frequently. The combustion chamber alterations did not appear to increase the engine's performance. The 19B engines suffered combustion blowouts above 17,000 feet and failed to restart on consistent basis. The 19XB-1 performed well at altitudes of 30-35,000 feet and had satisfactory starting characteristics. In addition, the 19B had difficulty starting at any altitude, while the 19XB-1 started satisfactorily up to 35,000 feet.[89]

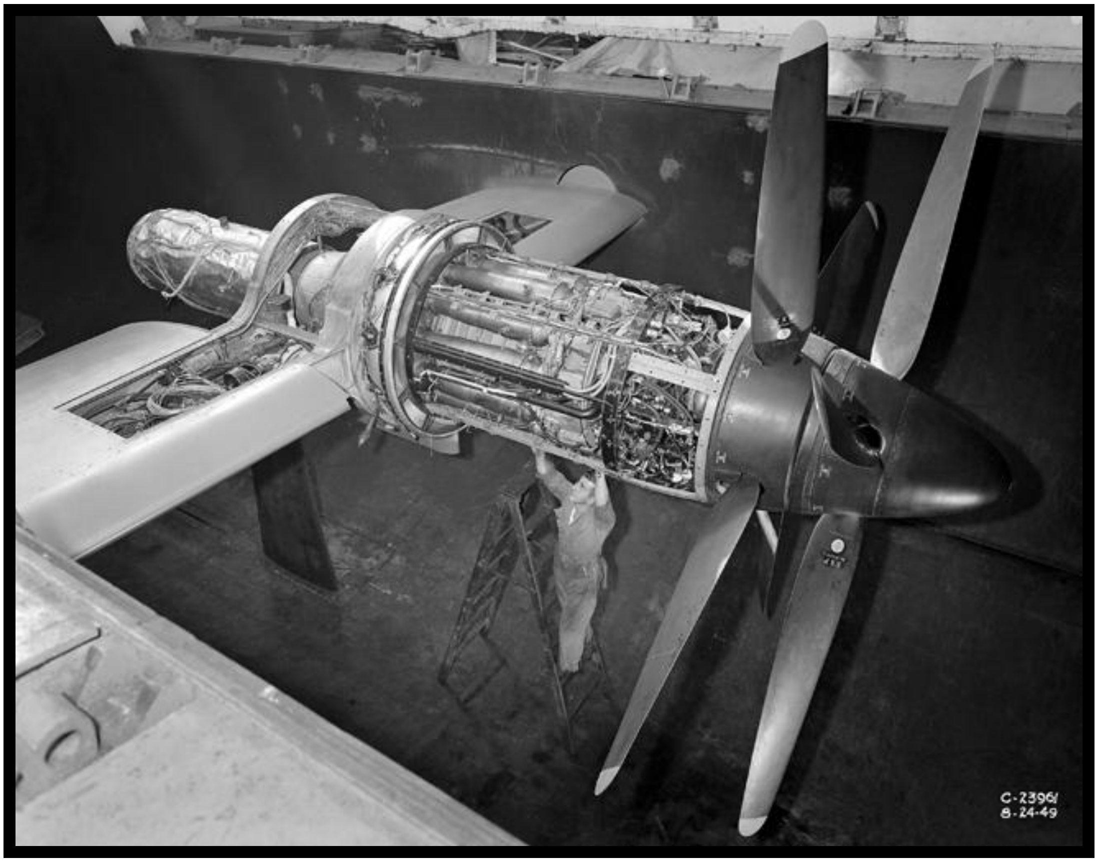
Another important early turbojet test was the Lockheed YP-80 Shooting Star with its GE I-40 engine. The Shooting Star was the first complete jet aircraft manufactured in the United States and was the first Air Force aircraft to fly faster than 500 mph.[90] Flight testing of the two YP-80As commenced in August 1944, and in early September the Air Force dispatched two to Britain and two to Italy to try to neutralize the Messerschmitt Me262's successes. Despite being placed on the highest priority, the YP-80As could not be produced in large enough quantities to have much of an effect in the war. It also continued to suffer operational problems, resulting in the deaths of several pilots.[91]

Similar to the Bell XP-59 tests, the entire YP-80A fuselage was installed in the AWT test section. One of the primary areas of research was the examination of the I-40's thrust performance at high altitudes and the attempt to predict that thrust from sea level measurements. AERL researchers were successfully able to create a curve for the I-40's thrust at all altitudes.[92]

Bell YP-80 Shooting Star installed in the Altitude Wind Tunnel test section
AWT Image No. 36: 1945-09446/NASA Glenn Research Center (1945)

Follow-up studies with the TP80S, a modified Shooting Star, found that turbine efficiency and compressor efficiency were not affected by altitude, but that combustion efficiency was reduced with increased altitude. Even though fuel consumption during normal engine speeds was unaffected, the engine's thrust was diminished with altitude.[93] After analyzing different tailpipes, it was determined that a short nozzle uniform diameter tailpipe outlet was most efficient.[94]

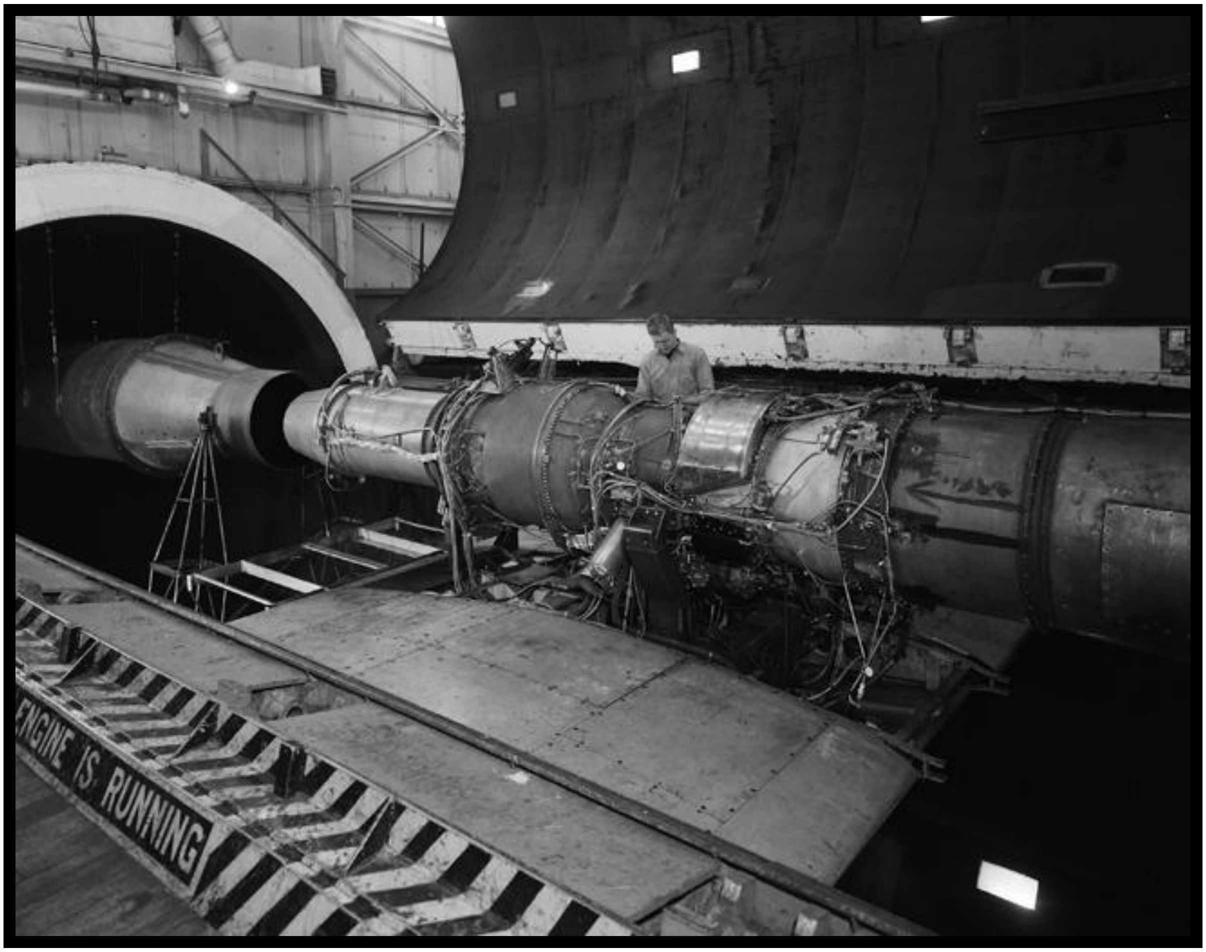
After the war, the majority of the AWT's research involved fundamental studies on the operational characteristics of aircraft engines and performance studies while the engine is firing. The researchers studied reciprocating, turbine-propeller, turbojet, ram jet, rocket, and compound engines. Most of which were tested under operating conditions across a full range of altitudes, velocity, and engine speeds. [95] The GE TG-180 and TG-190, and Westinghouse 24C were repeatedly studied in the tunnel. Testing of the GE TG-100A and the Armstrong-Syddeley Python turboprops were the basis for the successful Advanced Turboprop Program of the 1980s. The lab, including the AWT, spent a great deal of time studying the ram jet combustion process, but by the late 1950s the basic combustion process still had not been understood very well.[96]



Armstrong-Syddeley Python turboprop engine in the Altitude Wind Tunnel test section
AWT Image No.37: 1949-23961/NASA Glenn Research Center (1949)

The AWT was used to increase turbojet altitude range from 10,000 to 47,000 feet by increasing the combustion chamber. Diffuser alterations increased compressor efficiency by 15%. By studying the pressure readings throughout the diffuser revealed the cause of the problem which was easily fixed.[97] The AWT was also instrumental in the 15% improvement of turbojet ram pressure recovery as a result of redesign or air inlets.[98]

Jet engines grew in size and capabilities in the late 1940s and early 1950s. The second generation of turbojets was faster and more powerful. According to a 1955 NACA Lewis Budget Chart, turbojet thrust increased from 5000 to 30,000 pounds between 1948 and 1956.[99] Westinghouse J-40, Allison J-71 and T-38, Pratt & Whitney J57, and Rolls-Royce Avon engines were studied in the AWT during the early 1950s. The AWT was operating more in the early 1950s than any other point. It was also in use more often than any other major facility at the lab during this period.



Pratt & Whitney J57-P-1 jet engine in the Altitude Wind Tunnel test section
AWT Image No. 38: 1954-34637/NASA Glenn Research Center *(1954)*

The Pratt & Whitney J57 axial-flow dual compressor engine was one of the most enduring of the second wave of turbojet engines. The J57-P-1 was a development model which employed two co-axial compressors and corresponding co-axial turbines, and a fixed-area nozzle.[100] The 13,5000 pounds of thrust engine was used on the F-100 Super Sabre, B-52 Stratofortress, Lockheed U-2A, Boeing C-135, F-102, and numerous other aircraft. It was studied several times in the AWT.

At the request of the Navy's Bureau of Aeronautics, the engine's general performance characteristics were examined in the AWT from December 1953 until February 1954. This was followed by studies of fixed area nozzles, inlet pressure, and fuel flow characteristics. From January to May 1957, a number of different exhaust nozzles were tested on the J57 in an effort to stem excessive engine noise. [101]

The world was changing in the 1950s, and soon the interest in aeronautics would become subjugated to space. Lewis would play a prominent role in this new field. A series of AWT tests in the spring of 1955 served as a portent for the new era. Lewis researchers had been studying high-energy propellants for years. In the mid-1950s interest in liquid hydrogen as a propellant intensified. It was considered a dangerous material and it had to be stored cryogenically, but its low weight and high energy yield were unrivalled. Although it would go on to be a principle component of the space program, Director of Research, Abe Silverstein, initially conceived of it as propellant for long-range aircraft.

One of the early steps was determining if liquid hydrogen could be safely operated in an aircraft fuel system. In 1955 Lewis researcher Harold Kaufman conducted full-system tests of a liquid hydrogen fuel system with the J65-B-3 engine in the AWT. The system, which was identical to the one intended for use on a B-57 aircraft, was checked using both the jet fuel and hydrogen modes.

A couple of modifications allowed the engine to be tested at higher pressure levels and thus 25-30, 000 feet higher altitudes than previous AWT tests. Unlike earlier turbojet studies in the AWT, which used external make-up air, this test used tunnel air. This resulted in the exhauster having to only make up for tunnel leakage, rather than leakage plus external airflow.[102] This test also utilized an exhaust diffuser rather than the usual nozzle. With nozzles regulating the exhaust airflow, the tunnel pressure was less than half of the turbine's total pressure. The diffuser permitted the tunnel pressure to be almost the same as the turbine pressure.[103]

It was found that the jet fuel performance decreased significantly over 60,000 feet, while the hydrogen operated smoothly at at least 80,000 feet, and its blowout altitude exceeded the tunnel's 85,000 foot capabilities. Kaufman also found that the higher specific heat of hydrogen caused the turbine to produce a greater amount of thrust than obtained from jet fuel.[104]

During this test period Abe Silverstein and Eldon Hall wrote a report that foresaw liquid hydrogen performing missions which surpassed those of traditional hydrocarbon fuels.[105]

Although the switching between the jet fuel and hydrogen tanks was tested numerous times in the AWT with satisfactory results. Walter Olsen, Head of the Fuels and Combustion Division, felt that they had proven the systems ability with these extensive ground tests, but Silverstein insisted on a flight test.[106] Silverstein secured a contract to work with the Air Force to examine the practicality of a liquid hydrogen aircraft. The endeavor was termed Project Bee.[107]

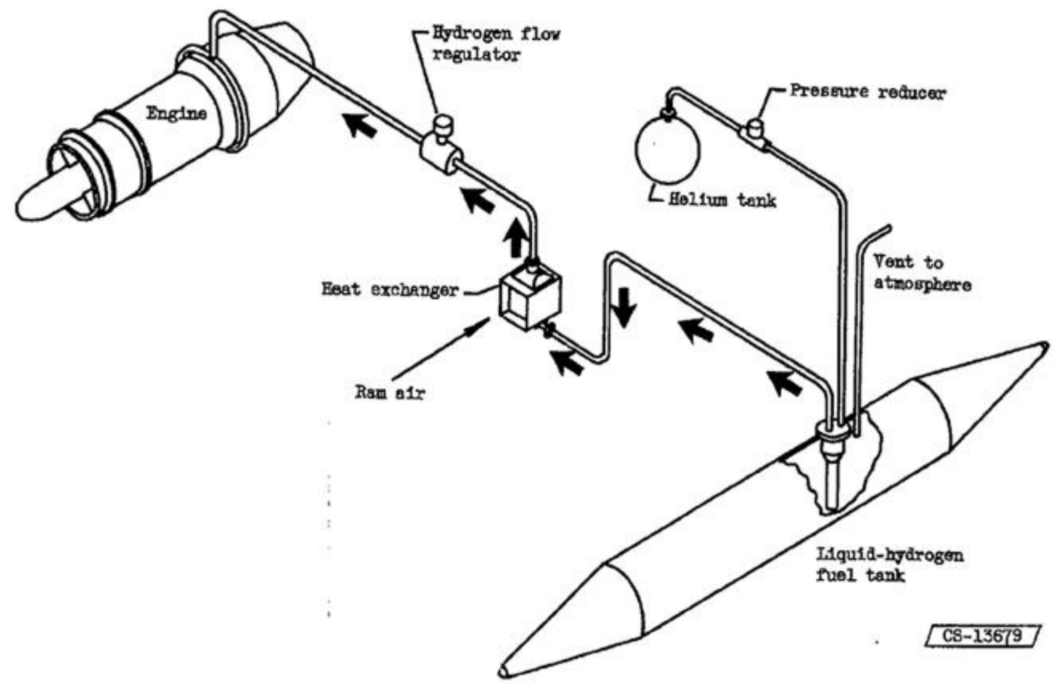


Figure 1. - Hydrogen flow system.

Liquid-hydrogen setup for test of the Wright J65-B-3 jet engine Altitude Wind Tunnel NACA AWT Image No. 39: RM-E57F13a Fig.1/NASA Glenn Research Center (1955)

A new B-57B aircraft was obtained by the Air Force especially for this project, and a liquid hydrogen production plant was built in nearby Painesville, Ohio. The aircraft was equipped with 23-foot long wing tanks, one of which was modified so that it could be operated using traditional or liquid hydrogen propellants. The other tank would be used to store helium which would be used to pump the hydrogen.[108]

Several dry-runs were flown in the fall of 1956, with the first attempt at hydrogen-powered flight on December 23, 1956. The intention was to take-off using jet fuel, switch to liquid hydrogen over Lake Erie, burn it all then switch back to jet fuel for the landing. The first two flights failed to make the liquid hydrogen switch. The third attempt in February 1957 was a success.[109] These flights would later be used to help convince NASA leadership that liquid hydrogen was safe to use for the Apollo Program.

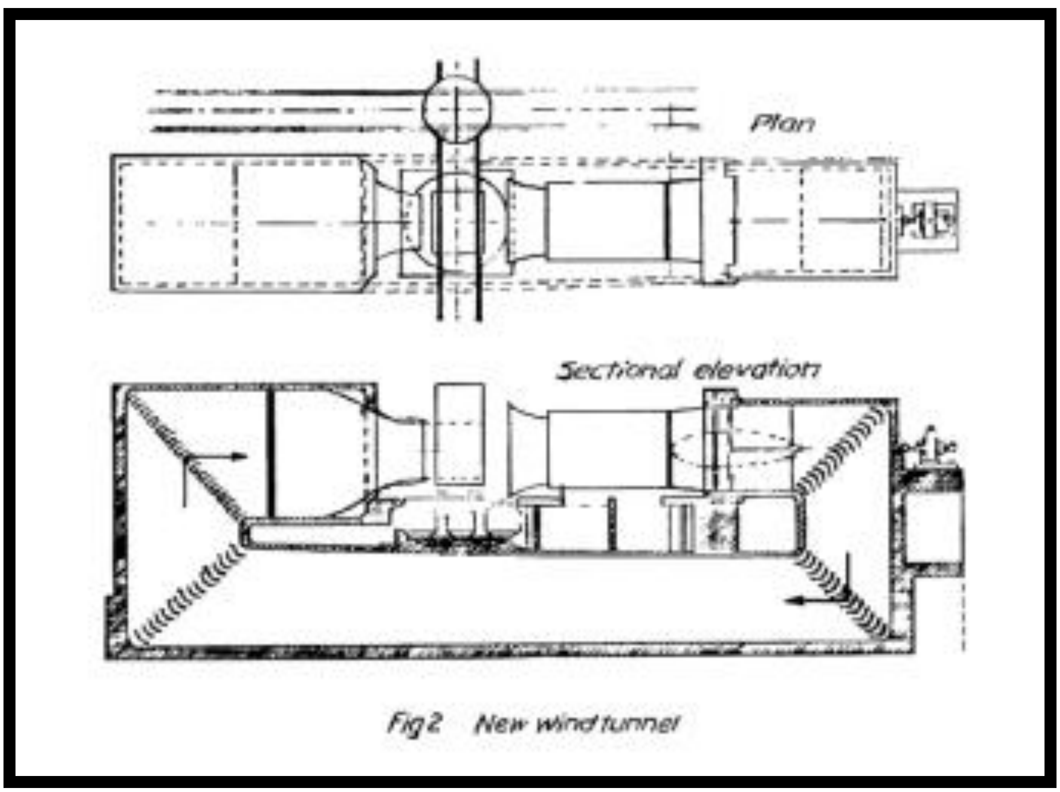
The lab constructed new, more powerful facilities such as the 8 by-6-Foot Supersonic Wind Tunnel (1949) and the Propulsions Systems Laboratory (1952). The 10 by-10-Foot Supersonic Wind Tunnel (1955) led to the decreased use of the AWT in 1956 and 1957 despite a major modernization project in 1951.

C. Contemporary Wind Tunnel Facilities:

Wind Tunnel Development: Although various methods of studying the principles of flight had been attempted before, the first true wind tunnel was created in Great Britain by Frank Wenham in 1871. Wenham constructed a 12-foot long wooden tunnel in which models could be inserted. A steam engine created the airflow through the 18 by-18-inch horizontal passageway.[110] In 1901 after several failures at Kitty Hawk, North Carolina, the Wright Brothers had built a tunnel similar to Wenham's in Dayton, Ohio. The 16 by-16 inch, 15-foot long, 27-mph tunnel produced important lift data for the Wrights.[111]

Earlier that same year, however, Albert Zahm built a 6 by-6 foot draw-through tunnel at Catholic University in Washington DC that dwarfed any of its contemporaries. Although Zahm's tunnel suffered problems due to uneven power levels and atmospheric instability, its method of airflow control and instrumentation would used by others for years.[112] Zahm's tunnel and those following benefited from the replacement of steam engines with more efficient electric powered engines which allowed greater wind speeds at a lower cost. [113]

Russia, France, and Great Britain all constructed substantial wind tunnels after the turn of the century.[114] The most influential, though, were Ludwig Prandtl's tunnels built at the University of Gottingen in Germany.



Drawing for Prandtl's second wind tunnel at the University of Gottingen, Germany
AWT Image No.40: NACA TN No. 66 Figure 2/NASA

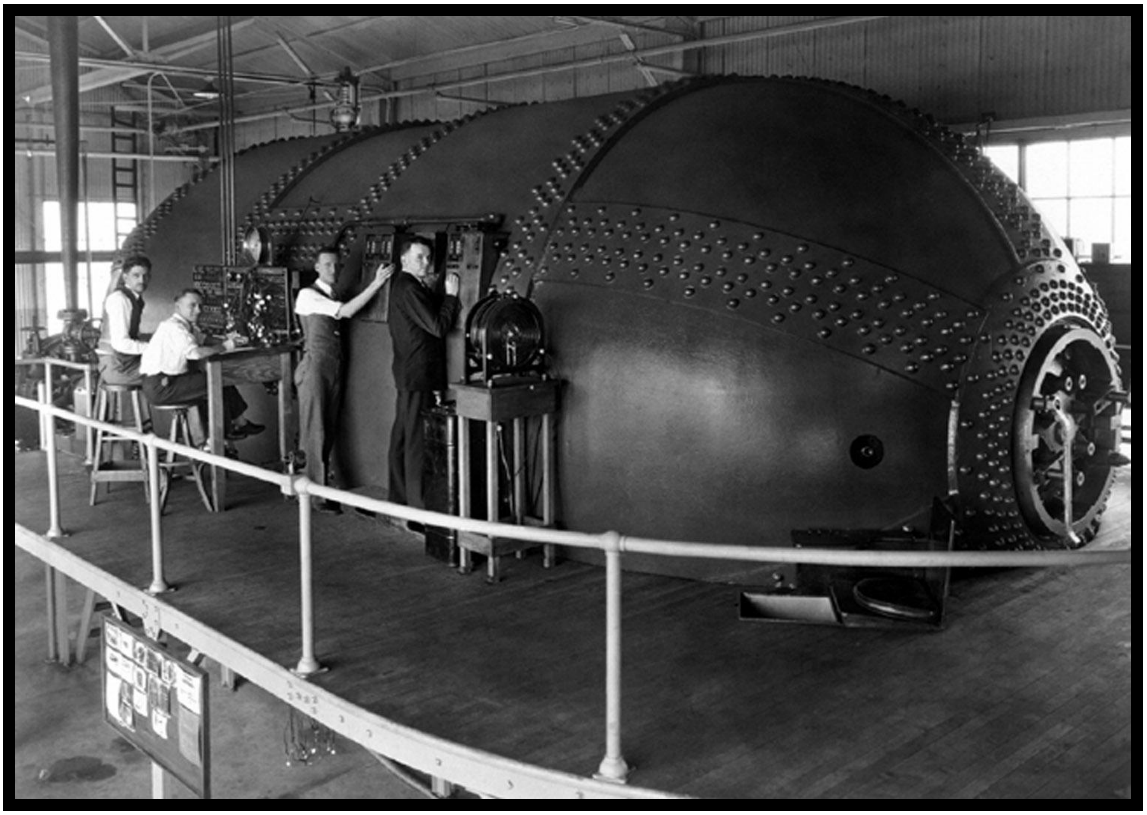
Prandtl's first tunnel was a rectangular closed-loop that used turning vanes in the corners and a honeycomb screen across the width of the tunnel to straighten and guide the airflow around the corners without losing energy. Although this new closed-loop design was revolutionary, from its first runs in 1909 this facility was seen as a stepping stone to a larger more complex tunnel.[115] Delayed by the war, Prandtl's second closed-loop tunnel did not become operational until 1917. The rectangular design allowed pressurization and humidity control and required less energy to operate since the airflow was recovered. The tunnel's throat was expanded upstream, narrowing sharply just before the test section to increase air speed to an unprecedented 120 mph.[116] Prandtl's tunnels were innovative in many ways and influenced almost all subsequent wind tunnels.

The aeronautical industry in the United States was also constructing wind tunnels. In 1916 with the foundation of his aircraft company, William Boeing built the 3 by-3-foot tunnel and donated it to the University of Washington in exchange for the foundation of an aeronautics program at the university. In 1936 the university began construction of the 8 by-6-foot 250 mph Kirsten Wind Tunnel that was used extensively on Boeing's B-29s during World War II.[117]

<u>NACA Wind Tunnels:</u> One of the primary motivations for the foundation of the Langley Memorial Aeronautical Laboratory in 1920 was the construction of a wind tunnel. Its first tunnel, however, a low-speed no-return facility built in 1920, was primarily a training tool whose data was not relevant to full-size aircraft.[118] The Variable Density Tunnel (VDT), proposed in 1921 by Dr. Max Munk, built on Prandtl's closed-loop tunnel and foreshadowed the sophisticated tunnels of future like the Altitude Wind Tunnel (AWT). Munk had been a student of Prandtl's at Gottingen and had designed a massive, but unbuilt pressurized tunnel for the Zeppelin company.[119] The VDT was the US first tunnel to forgo normal airflow for highly pressurized air. The tunnel used a large steel tank in which the atmosphere could be pressurized, but maintained a wooden test section to negate Reynolds number concerns.[120] The VDT pressure tunnel, which became operational in 1923, could subject large-scale models up to speeds of 250mph and sub-atmospheric up to several atmospheres.

Langley began putting an entire collection of increasingly complex wind tunnels into operation. The next was the Propeller Research Tunnel (PRT) in 1927, followed by the Vertical Spin Tunnel and Atmospheric Wind Tunnel in 1930, the Full Scale Tunnel in 1931, the 8-Foot High Speed Tunnel (HST) in 1936, and the 19-Foot Pressure Tunnel of 1939. The HST, which could simulate pressure altitudes of 12,000 feet and speeds of 500 miles per hour, and the 19-Foot, which combined a large test section with 250 mile per hour speeds, were significant steps forward in flight simulation.[121]

The PRT was the nation's first tunnel built to study aircraft engines. Although it was an atmospheric tunnel and could generate speeds up to 100 mph, it was significant because entire airplanes with their engines running were tested. The AWT would take this concept to the next level, by testing full-scale engines in actual flight conditions and at higher speeds.



The Variable Density Wind Tunnel at the NACA's Langley Memorial Laboratory
AWT Image No. 41: GPN-2000-001242/NASA

The first supersonic tunnel in the United States was a 9 inch Mach 2.5 Langley tunnel put into operation in July 1942. Three years later, Langley began work on a 4 by 4 foot supersonic tunnel.[122] The wind tunnels at Langley became used more and more for the development of military aircraft as World War II approached. This testing grew to such a level that by 1939 the tunnels were operating 24 hours a day so that basic research could continue as well.[123]

Two identical 7-Foot by 10-Foot tunnels and a 16-foot diameter tunnel were constructed at the NACA Ames Aeronautical Laboratory as planning for the Cleveland engine lab was beginning. The massive 40 by 80 foot Full Scale Wind Tunnel at Ames was added by 1944. In 1942 the NACA operated eleven wind tunnels between Ames and Langley. By 1948 there were 25, including five in Cleveland.

Altitude Wind Tunnels: New German wind tunnels in the early 1940s included three supersonic tunnels at Peenenmunde, a 280 mph tunnel with an almost 9 by-9-foot test section, a vertical spinning tunnel, a 20 by-30-foot tunnel, and others. As post-war Allied expeditions discovered, two hypersonic tunnels, a Mach 7 to 10 tunnel, a 9 by-9-foot supersonic tunnel, numerous small supersonic tunnels, and an altitude wind tunnel were among the facilities being prepared for operation when the war ended.[124]

The National Bureau of Standards, Naval Aircraft Factory, and the Army Air Corps'Wright Field had successfully designed pressure tanks that could simulate the temperature and pressures associated with altitude, but they could not incorporate the benefits of a wind tunnel. On the other hand, Wright Brothers Wind Tunnel at the Massachusetts Institute of Technology (MIT), completed in 1939, could simulate altitudes of 37,000 feet with speeds of 400mph in a wind tunnel setting but was not capable of running aircraft engines during the test. MIT began constructing wind tunnels in 1914 under the supervision of future NACA Director Jerome Hunsaker. The Wright Brothers Wind Tunnel was used extensively throughout World War II and remains active as a training tool for MIT students.[125]

Construction on the wind tunnel complex at Wright Patterson Air Force Base that included the 10-Foot Wind Tunnel that could simulate altitude conditions up to 50,000 feet. The 10-Foot Wind Tunnel became operational in January 1947 and was closed in 1957.[126] The S1-MA wind tunnel located in the French Alps is capable of firing engines at altitudes up to 20,000 feet. ONERA, the French Aerospace Research Institute, built the tunnel in 1952 at Mondane-Avrieux. It is powered by water turbines and includes spray bars to conduct icing tests when the ambient air is cold enough.[127]

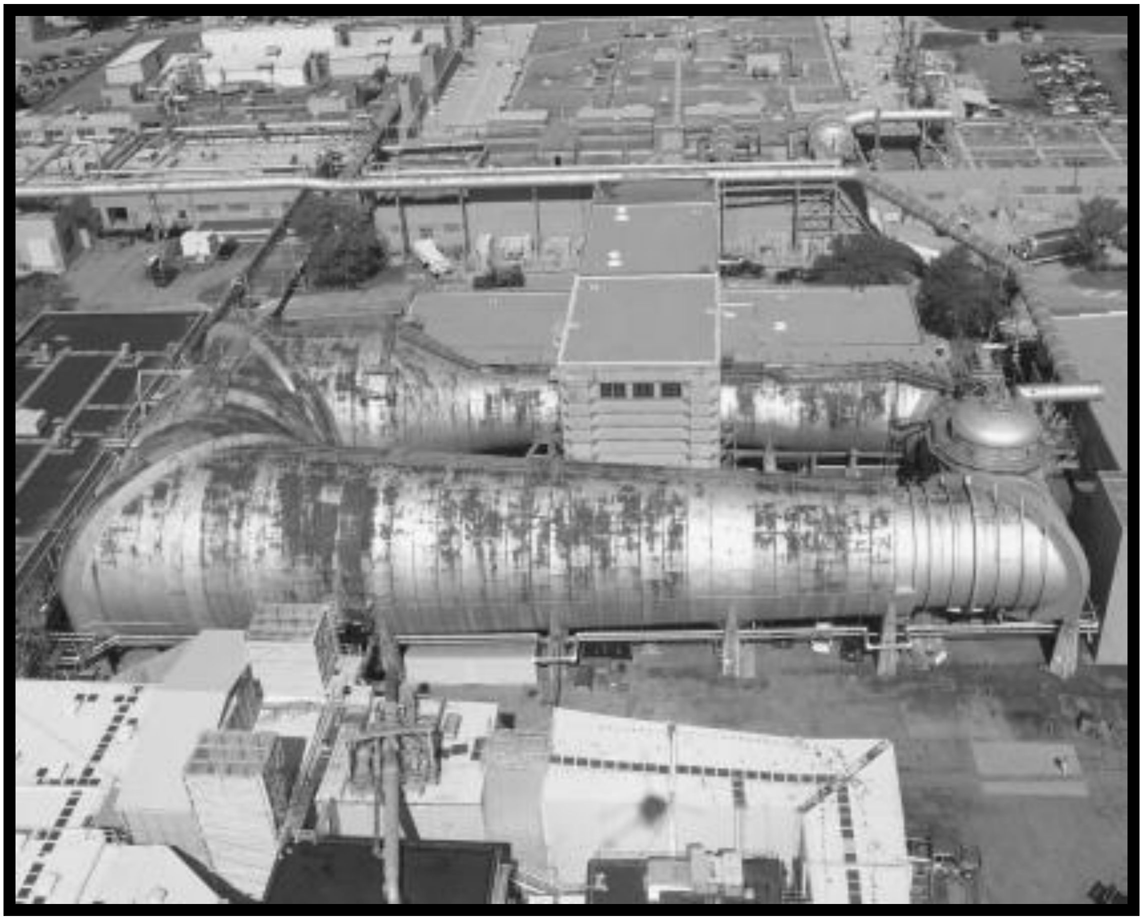
The Propulsion Wind Tunnel (PWT) at Arnold Engineering Development Center (AEDC) was capable of testing jet and rocket engines at altitudes and at much higher speeds than the AWT. The PWT only operates at speeds above Mach .55, though, so it is incapable of producing low-speed altitude conditions. It began operation in 1956 and The maintains an active test schedule today.[128] The AEDC facilities in general tend to be used more for the qualification and development of engines, while NASA Glenn's facilities are geared more for research and the study of engine dynamics.[129]

Part II. Architectural Information—Altitude Wind Tunnel

AWT from east with Icing Tunnel (left), Engine Research Bldg (right), Propulsion Systems Lab (top)
AWT Image No. 42: 1955-39059/NASA Glenn Research Center (1955)

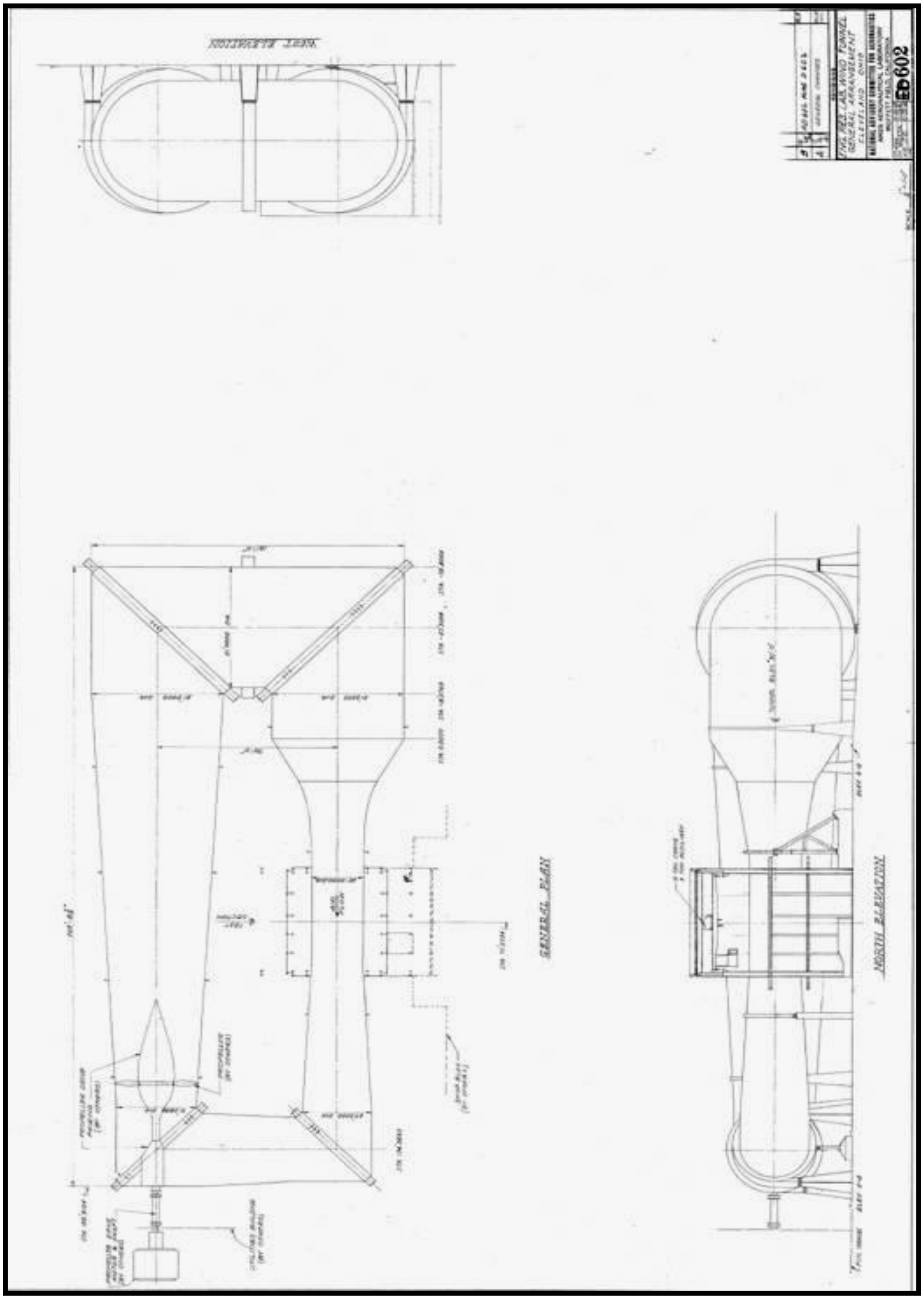
Wind Tunnel:
The Altitude Wind Tunnel (AWT) was the NASA Glenn's (then the NACA's Aircraft Engine Research Laboratory) first and largest wind tunnel until it was converted into space test chambers. Its central location at the lab allowed it to interact with several other facilities and buildings, including the Icing Research Tunnel, Engine Research Building, and Propulsion Systems Laboratory.

The AWT itself required a large amount of infrastructure and several support buildings. These included the Shop and Office Building, the Exhauster and Refrigeration buildings, Cooling Tower No.1, and the Air Dryer Building. The facility was powerful enough to support several small wind tunnels.



View from the south of the Altitude Wind Tunnel
AWT Image No.43: 2007-02575/NASA Glenn Research Center (2005)

The tunnel was 263 feet long on the north and south legs, and 121 feet long on the east and west legs. The larger west end of the tunnel was 51 feet in diameter throughout. The east side of the tunnel was 31 feet diameter at the southeast corner and 27 feet diameter at the northeast. The throat section, which connected the northwest corner to the test section in the middle of the long northern leg, narrowed sharply from 51 feet to 20 feet in diameter. The test section was 20 feet in diameter. The courtyard inside the tunnel loop was 168 feet long and approximately 40 feet wide at the east end, 18 feet at the west end. [130]



Elevation and layout drawing of the AWT
AWT Image No. 44: ED-602-01/NASA Glenn Research Center

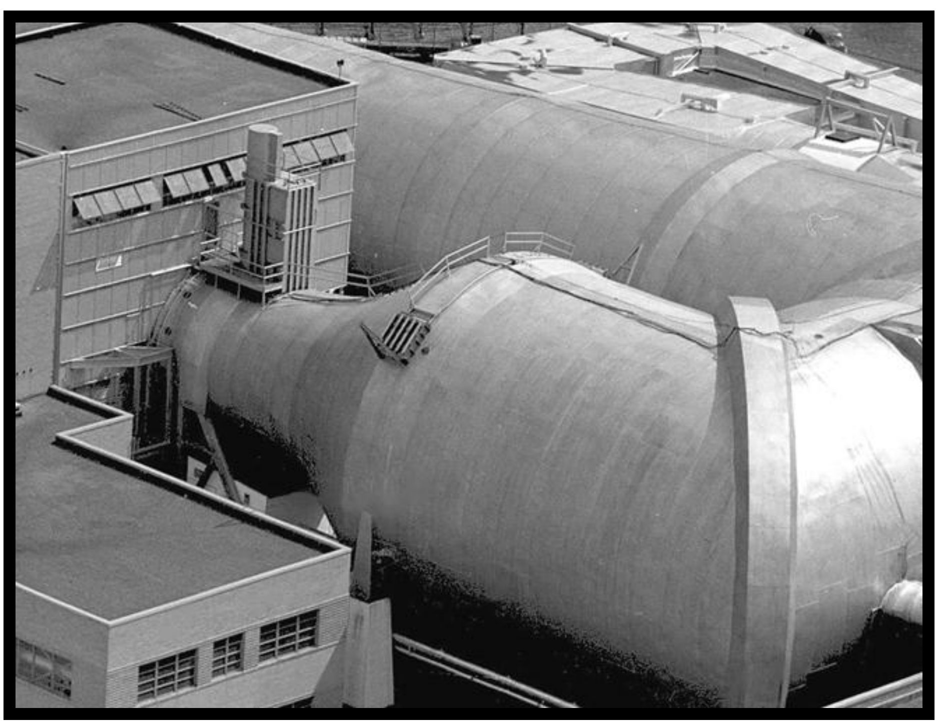
View from southeast corner of AWT and test chamber before walkways were installed
AWT Image No. 45: 1945-10528/NASA Glenn Research Center (1945)

View facing east of the AWT's south leg
AWT Image No. 46: 2005-01488/NASA Glenn Research Center (2005)

Westward view from throat section of northwest corner of AWT
AWT Image No. 47: 1945-10525/NASA Glenn Research Center (1945)

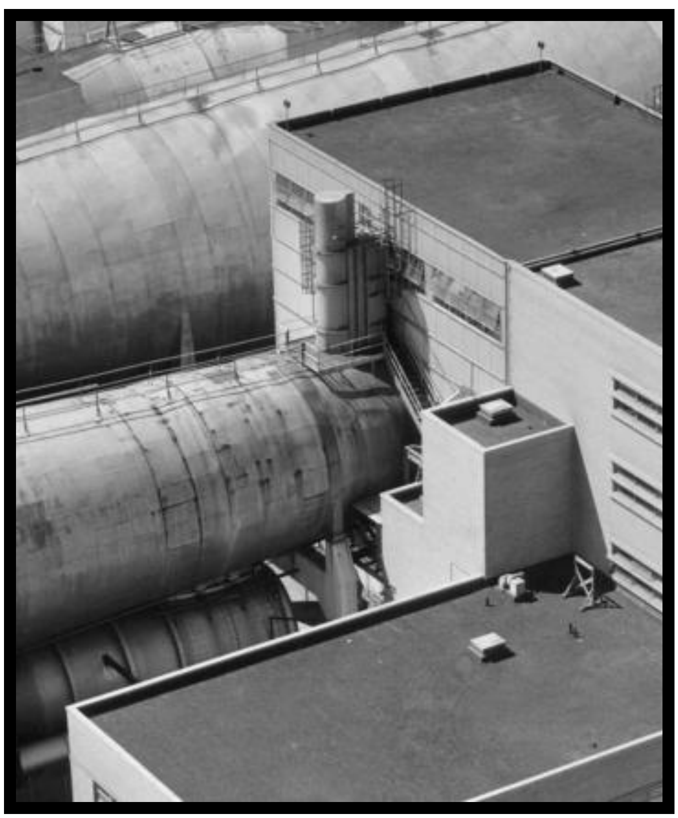
Northwest leg of the Altitude Wind Tunnel as seen from the north
AWT Image No. 48: 2005-01467/NASA Glenn Research Center (2005)

AWT Image No. 49: 2005-01469/NASA Glenn Research Center (2005)



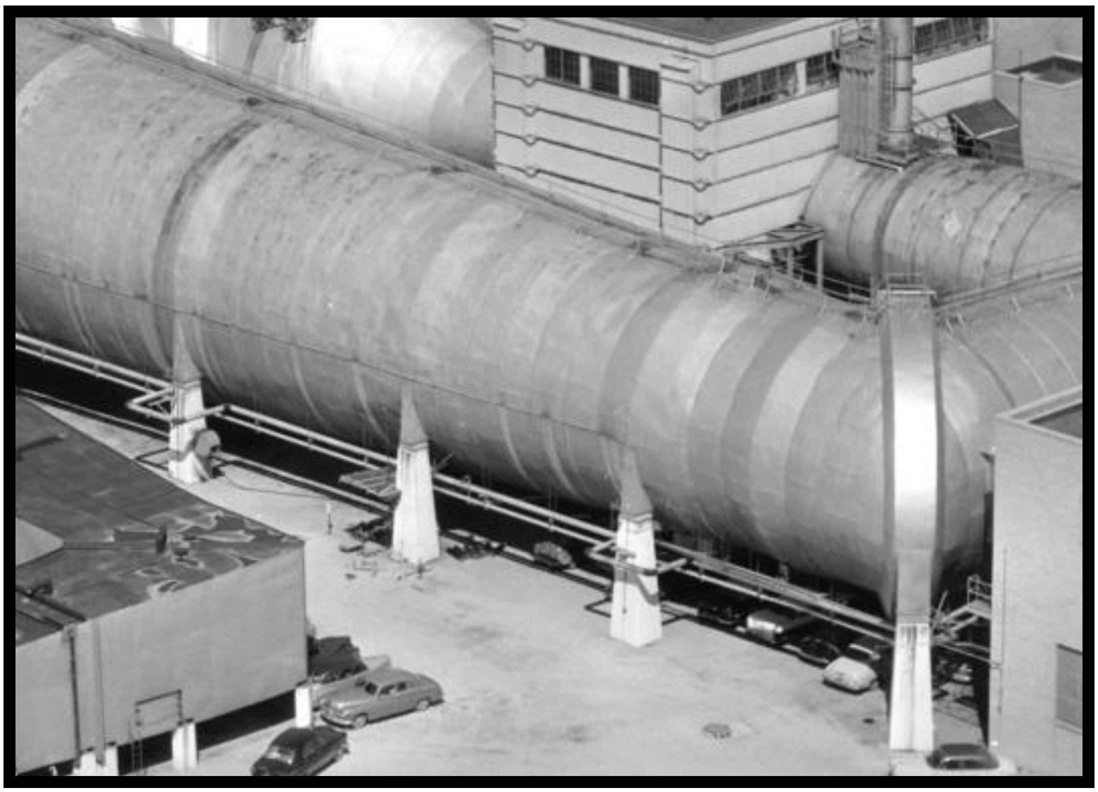
Views from northeast of the AWT's throat section as it enters the test chamber
AWT Image No. 50: 1945-13054/NASA Glenn Research Center (1945)

View facing east of northeast leg of the Altitude Wind Tunnel
AWT Image No. 51: 2007-02571/NASA Glenn Research Center (2005)



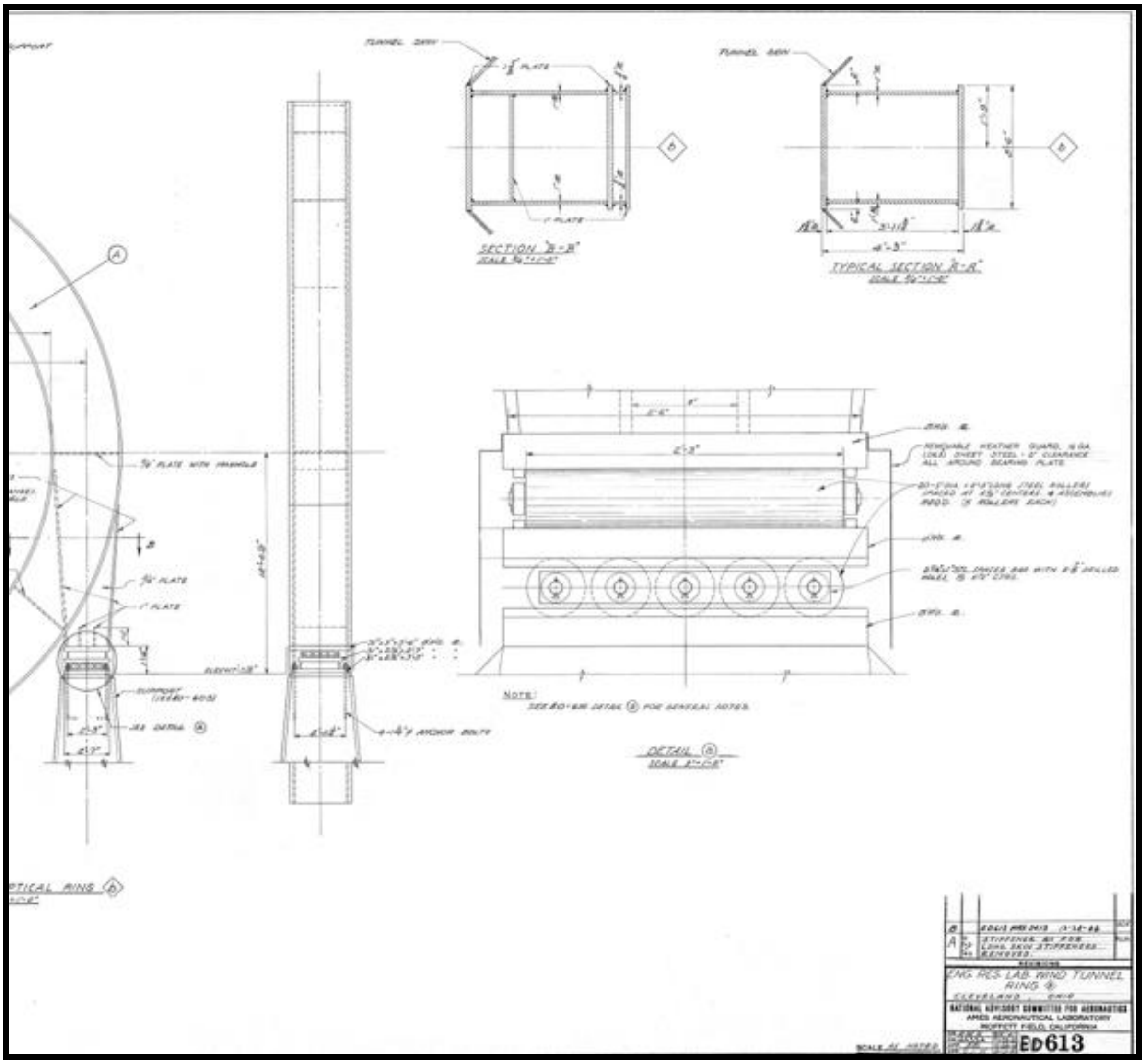
View from northeast of the AWT as it exits the east wall of the test chamber
AWT Image No. 52: 1955-38784/NASA Glenn Research Center (1955)

Structure/Foundations: The tunnel was supported by a large elliptical support ring in each corner, the Shop and Office Building's test chamber, and a series of 120 support rings which lined the tunnel at 6-foot intervals. Eight of these 120 support rings and the 4 larger corner rings were anchored to concrete piers which elevated the tunnel at varying heights.[131] These six primary support rings ranged from 9 to 11 feet wide at base and 3 to 3.5 feet wide at top and in height from 23 to 27 feet 8 inches.[132]



View from southeast showing some of the AWT's support rings, concrete pylons, and a corner ring
AWT Image No. 53: 1955-38785/NASA Glenn Research Center (1955)

The tunnel was elevated using unique concrete and steel piers. The midpoint of the twelve main rings connected to vertical steel supports. Steel rollers between the piers and the rings were used to bear the tunnel shell in a way that allowed the shell to contract and expand during the tunnel's dramatic temperature and pressure fluctuations. The 1-foot 10-inch long and 4-inch diameter rollers were connected at the tips to horizontal steel spacer bars. One row of five rollers was stacked perpendicularly on a second row of five rollers. These layers were attached to beveled base on top of the pier.[133]



Drawing of steel roller setup
AWT Image No. 54: ED 613 01/NASA Glenn Research Center

Concrete pylon, supporting northeast corner of AWT, with rollers exposed between the concrete and steel
AWT Image No. 55: 2005-01473/NASA Glenn Research Center (2005)

Westward facing view of south leg of the AWT with rust highlighting the support rings
AWT Image No. 56: 2005-01486/NASA Glenn Research Center (2005)

Below the rollers the pier was encased in a concrete pylon which extended 2 ½ to 3 feet into the ground.[134] The wide western end of the tunnel rested on the ground but had a large concrete support in the V-shaped area. Fourteen concrete pylons of varying sizes supported the other portions of the tunnel. These were laid out in pairs with one on the exterior of the tunnel and another inside the loop.[135]

The throat section was supported by the balance chamber.[f] The external portion of this support consisted of two vertical and two diagonal I-beams on each side of the tunnel with a web of smaller horizontal and vertical steel beams. These beams were sunk into a single concrete base approximately 48 inches in height and 22 feet in width. An H-shaped concrete support bore the weight of the tunnel on each end as it entered and exited the test chamber. By 2005 the concrete and steel pylons showed rust and some scaling.

[f] For additional information on the balance chamber, see the page of this section of the report.

AWT Image No. 57: 1945-10526 & 2005-01482/NASA Glenn Research Center (1945)

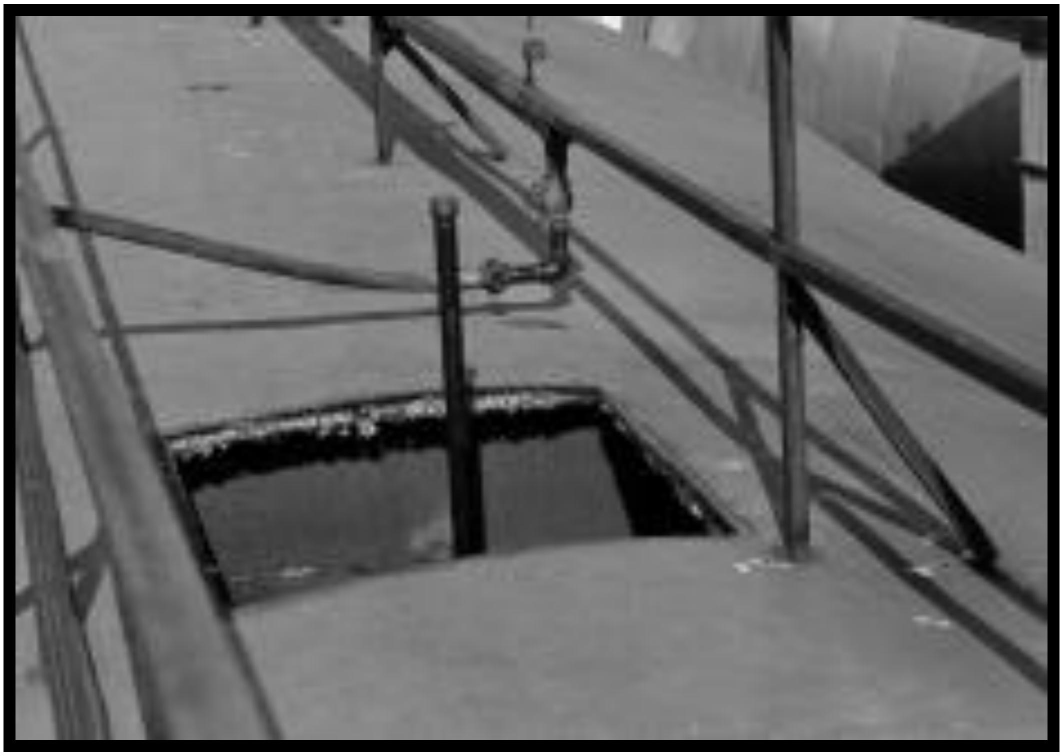
1945 and 2005 views facing west inside the AWT loop showing the pylons and west end concrete base
AWT Image No. 58: 2005-01482/NASA Glenn Research Center (2005)

View facing west inside the AWT loop with Space Power Chamber at far end and throat support to left
AWT Image No. 59: 2005-01483/NASA Glenn Research Center (2005)

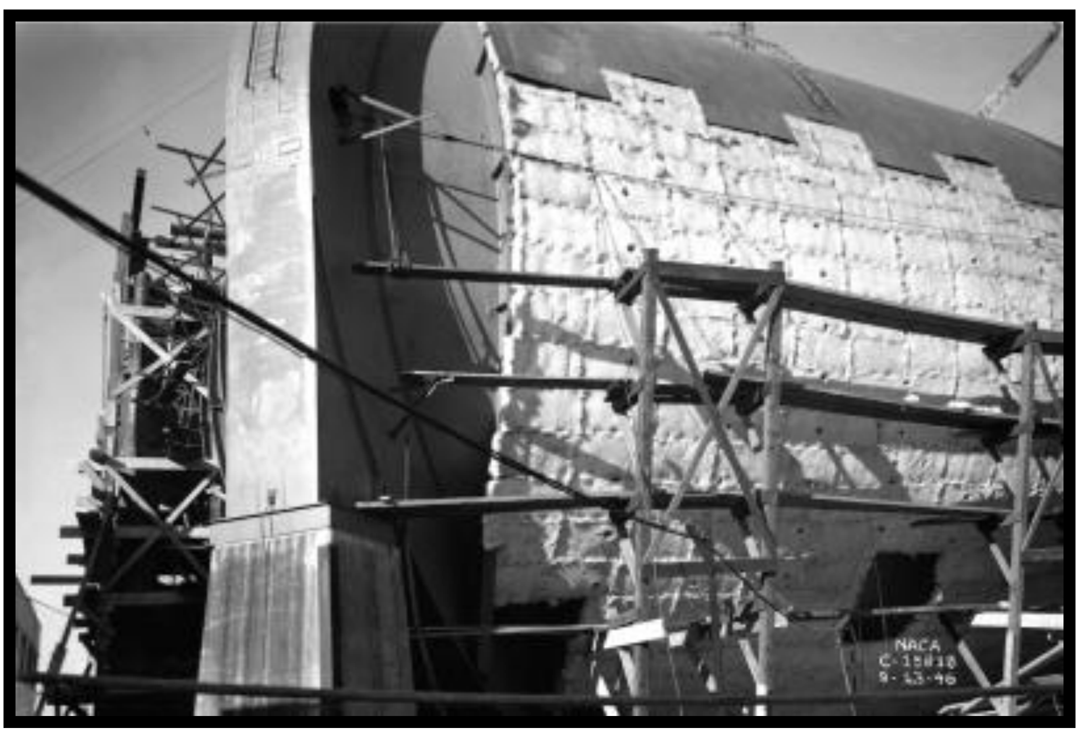
H-shaped concrete support under tunnel as it exits the east wall of the test chamber
AWT Image No. 60: 2005-01471/NASA Glenn Research Center (2005)

Shell: The AWT's shell consisted of two layers of steel with a layer of insulation in-between. The inner steel layer was the primary tunnel structure. Because of the AWT's altitude simulating capability, the steel used to construct the shell was both thicker and stronger than that used on other contemporary tunnels. The 1-inch thick steel could withstand external pressure when the tunnel was evacuated to simulate high altitude pressure levels. A chromium and copper-based steel alloy was used to endure the low temperatures of the high altitudes without becoming brittle.The chromium provided extra hardness, and the copper was used to resist corrosion.[136]

View of southeast corner of AWT showing thin outer shell (l) an d thicker inner shell & support rings (r)
AWT Image No. 61: 1961-58121/NASA Glenn Research Center (1961)



Opening in AWT's tunnel shell revealing thin outer steel layer and fiberglass insulation
AWT Image No. 62: 1951-27825/NASA Glenn Research Center (1951)



View facing northeast showing the application of fiberglass insulation and outer protective plate.
AWT Image No. 63: 1946-15818/NASA Glenn Research Center (1943)

A 4-inch layer of asbestos-based glass wool was installed with steel mesh over the inner tunnel shell to retain the tunnel's low operating temperatures. The outer 1/8-inch steel shell was then constructed over this to protect the insulation from the environment.[137]

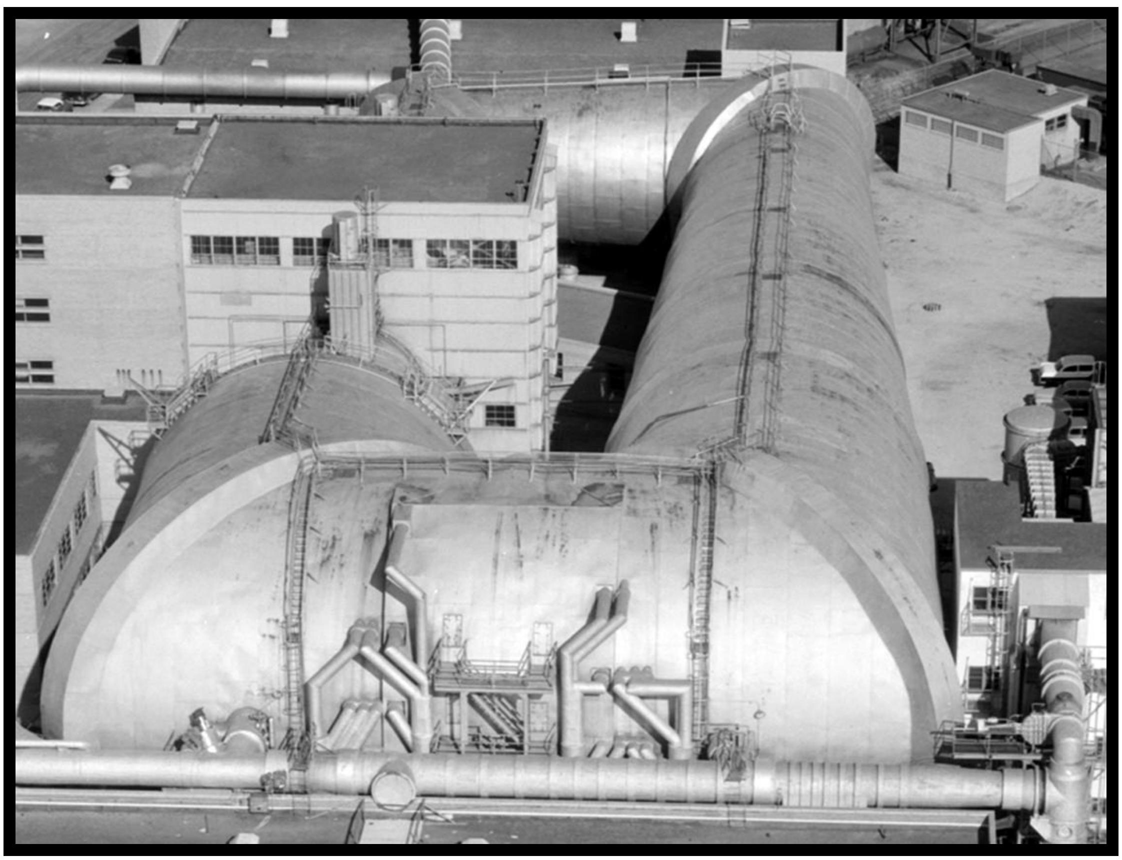
The outer shell of the tunnel was composed of 6-foot by 6-foot steel squares welded vertically in succession in between each of the 120 support rings and four corner rings. Two of these forms were welded together to form would form a single section of the tunnel.[138] The exterior of the tunnel was relatively smooth except for the four corner rings which jutted out several feet. The valve that connected to the Small Supersonic Tunnel Building jutted out on the southern leg near the west corner, but was sealed off in the 1980s. The east side of the tunnel included a portal for the drive shaft in near the southeast corner and the exhaust pipe near the northeast corner.[g] The western side had a number of cooling system ports and the two make-up air valves. It also possessed a metal stairway providing access to the cooling line ports.

View of southeast corner of AWT showing with rust outlining the outer shell's square steel panels
AWT Image No. 64: 2005-01670/NASA Glenn Research Center (2005)

[g] Alterations to the eastern end of the tunnel roof in the 1960s are discussed in the Space Power Chamber portion of this document.

Roof: By the mid-1940s, a series of stairs, ladders, and platforms were built on the roof of the tunnel. Access was provided by doorways off the east and west sides of the test chamber. The walkway originally led from the west door over the throat section with stairs leading to the top of the west end of the tunnel. The walkway, interrupted only by the four corner rings, followed the top of the tunnel until ending at the west side of the test section. Small permanent ladders and platforms were used to climb over the corner rings.[h] The pathway had a steel handrail approximately 3 feet high with a second horizontal bar segmenting it. Steel grated platforms replaced the original wooden platforms by mid-1945.[139] In 2005 the walkway and its components were rusted but in relatively good shape.

The coating of the tunnel with a protective grey paint appears to have ceased in the mid-1990s. Rust began to appear on the exterior of the tunnel by 1999 and was extensive by 2005. The outer shell of the tunnel on the roof bowed under human weight.



View from west of walkway running along the roof of the Altitude Wind Tunnel
AWT Image No. 65: 1955-38654/NASA Glenn Research Center (1955)

[h] Alterations to the eastern end of the tunnel roof in the 1960s are discussed in the Space Power Chamber portion of this document.

Interior Walls: The interior of the tunnel was smooth and tubular except for the corners. The approximately 3-foot wide corner ring surfaces were squared but flush with the tunnel walls. The inner tunnel nexus at the western end had an approximately 3-foot wide flat ramping piece that separated the north and south legs. The steel walls were composed of 52-inch long and 60-inch wide rectangular steel plates aligned vertically.

During the tunnel's operation, the long south leg housed the drive fan. The interior of the south leg had few obtrusions except several eyehooks which were welded to the lower walls for shroud separation tests in the Space Power Chambers.[i] In recent years several rectangular several square holes were cut into the lower half of the tunnel walls which reveal the insulation, mesh, and outer shell.

View east of interior of the south leg of the AWT with fan without its faring at far end
AWT Image No. 66: 1961-57710/NASA Glenn Research Center (1961)

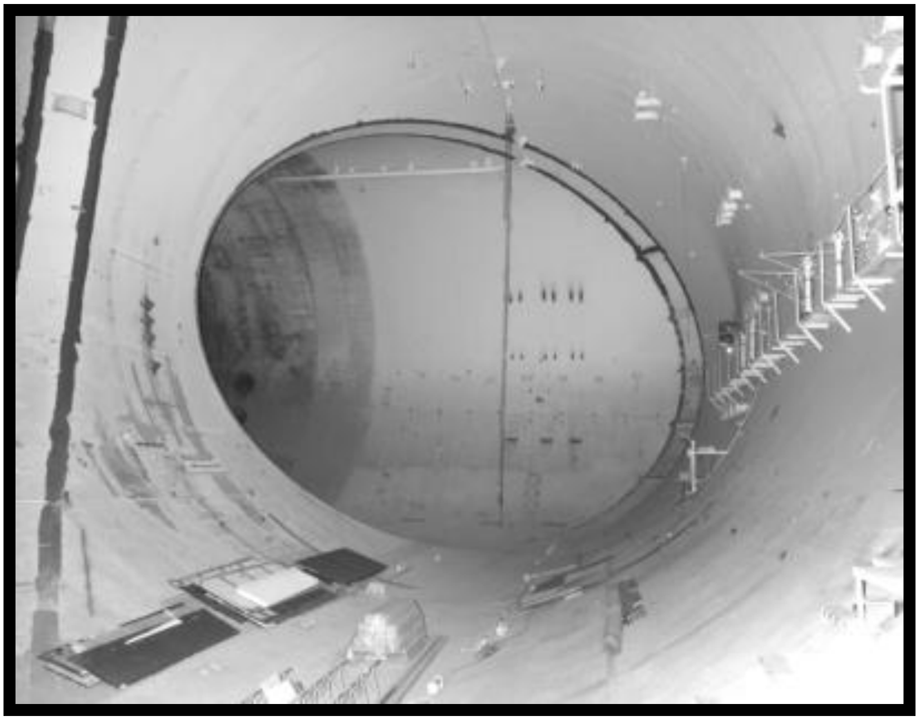
[i] A full description of alterations for the Project Mercury tests can be found in the Space Power Chamber section.

View from east of south leg of the Altitude Wind Tunnel
AWT Image No. 67: 2007-00386/NASA Glenn Research Center (2007)

View from west of the south leg of the Altitude Wind Tunnel
AWT Image No. 68: 2007-00380/NASA Glenn Research Center (2007)

Interior of AWT south leg where drive fan was formerly located
AWT Image No. 69: 2005-01630/NASA Glenn Research Center (2005)

One of a series of holes cut into the southern leg showing the tunnel's shells, mesh, and insulation
AWT Image No. 70: 2005-01625/NASA Glenn Research Center (2005)



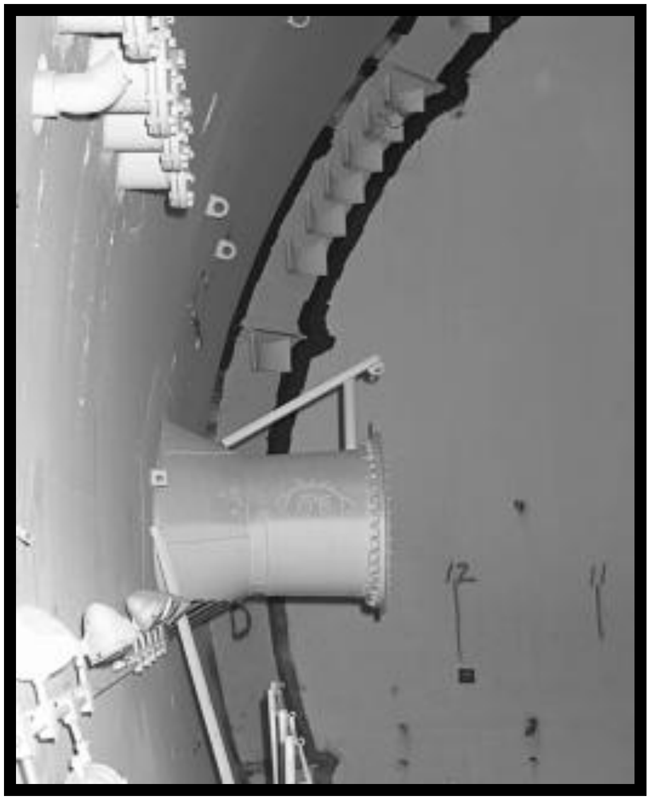
AWT Image No. 71: 2005-01476/NASA Glenn Research Center (2005)

View facing south of the wide western leg of the AWT with cooling coils and turning vanes removed
AWT Image No. 72: 1963-65547/NASA Glenn Research Center (1963)

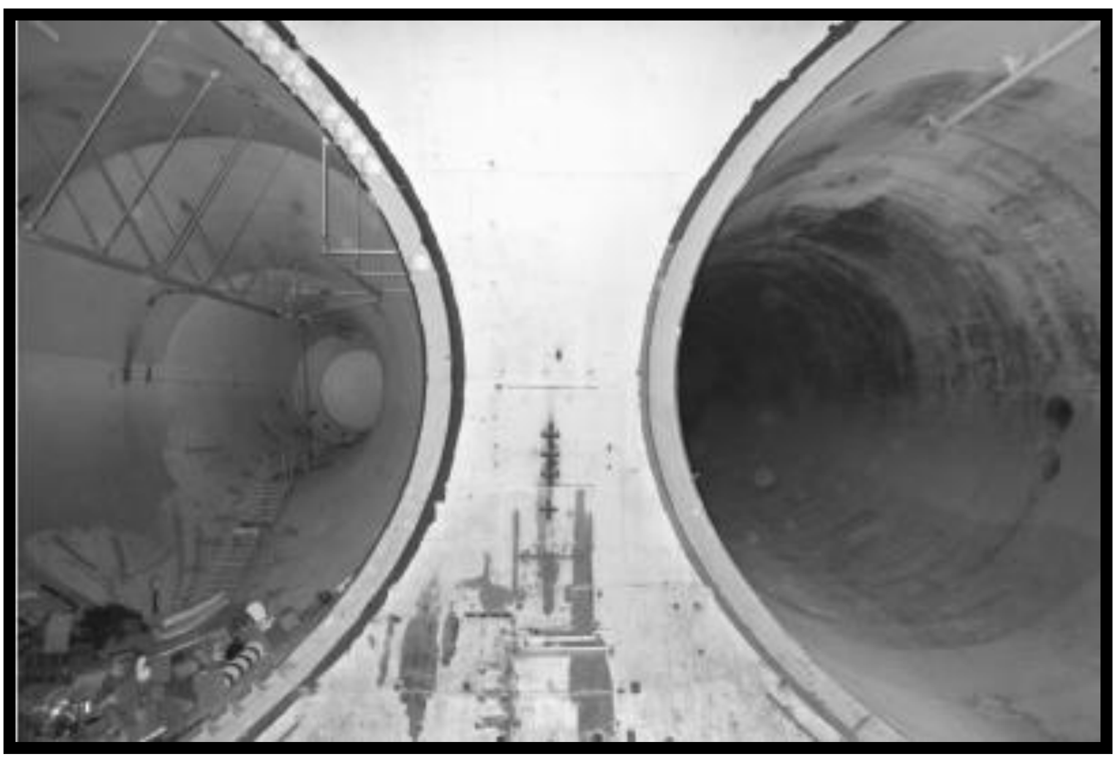
The wide 51-foot diameter western leg contained the make-up air nozzles, cooling coils, and turning vanes during the facility's years as a wind tunnel. Although these items were removed in 1959, the interior of the western wall still had a large number of obtrusions.[j] The northern and southern sections of the wall each contained make-up air nozzles and three rows of four and one row of two smaller nozzles that fed the cooling coils. These were severed and capped in 1959.

Western wall of the AWT showing sealed penetrations for refrigeration lines to cooling coils
AWT Image No. 73: 2005-01610/NASA Glenn Research Center (2005)

[j] Description of modifications to create vacuum chamber described in Space Power Chamber portion of this report.



Northward view of west wall showing refrigeration lines above and sealed make-up air nozzle
AWT Image No. 74: 2005-01621/NASA Glenn Research Center (2005)



View looking east down both main legs of the AWT from west wall
AWT Image No. 75: 2005-01615/NASA Glenn Research Center (2005)

The throat section narrows in the span of 30 feet from 51 feet in diameter at the northwest corner to 20 feet in diameter at the test section. This contraction accelerated the airflow to maximum speed through the test section.

View west from throat section in the northwest leg of the AWT
AWT Image No. 76: 2007-00392/NASA Glenn Research Center (2007)

View of the throat section from northwest corner of the AWT
AWT Image No. 77: 2007-00387/NASA Glenn Research Center (2007)

View from throat section through former 20 foot diameter test section with air scoop at far end
AWT Image No. 78: 1961-57715/ NASA Glenn Research Center (2005)

Eastward view from test section through northeast tunnel section after air scoop removed
AWT Image No. 79: 2007-02565/NASA Glenn Research Center (2005)

View facing south of eastern leg of AWT with a set of turning vanes and the fan's drive shaft
AWT Image No. 80: 1944-03393/NASA Glenn Research Center (1944)

The eastern leg was mostly obstruction free except the drive shaft passing through the southeast corner and the exhaust pipe in the northeast corner.[k] The shaft removed and the portal sealed in 1961.

In 2007, the overall condition of the interior of the tunnel was fairly good considering it had not been painted in over thirty years. The walls did have some rusting, particularly near the southeast corner and along the seams. The welds at the support ring seems were numbered with spray paint in recent years.

[k] Ibid.

View south of eastern leg of AWT as it appeared after conversion to vacuum chamber
AWT Image No. 81: 2007-02570/NASA Glenn Research Center (2005)

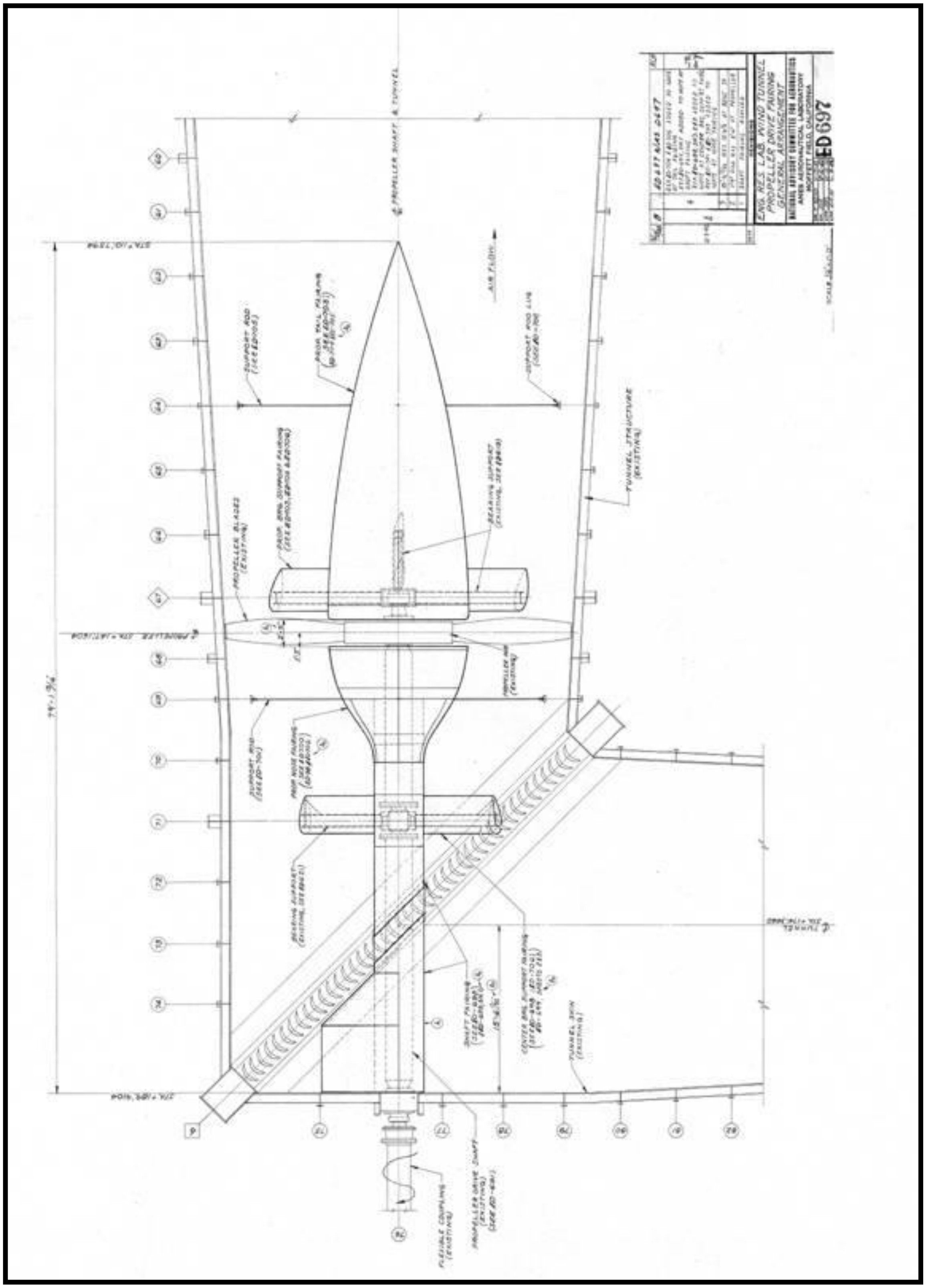
Sealed penetration where the drive shaft for the AWT's fan was formerly located
AWT Image No. 82: 2005-1642/NASA Glenn Research Center (2005)

Airflow System:

Drive Fan: The tunnel's airflow was set in motion by a 31-foot diameter, 12-bladed spruce fan in the southeast corner of the tunnel. The Langley-designed fan could create wind speeds up to 500 miles per hour at higher altitudes. The base of each blade was wedge-shaped so that when all the blades were assembled the bases formed a solid oval. A large wooden bearing held the fan to the drive shaft. The propeller was protected from debris by a bronze screen.[140] Despite this, the propeller blades did become damaged over time and sometimes snapped. They were regularly inspected and periodically replaced.

A large conical tail faring was affixed to the shaft with a vertical support bearing that ran from the floor to the ceiling at 25 feet 3 inches into the east end of the tunnel. There was also a shorter, widening nose faring facing upstream. The wooden propeller was attached to the shaft at approximately 42 feet 9 ½ inches from the east tunnel wall. Less than 2 feet further downstream were another three vertical support bearing and two diagonal supports to the floor. These supports hold the tail faring which came to a point downstream.[141]

View from the west of the original AWT fan, tail faring, and supports with a set of turning vanes behind
AWT Image No. 83: 1944-03992/NASA Glenn Research Center (1944)



Drawing of AWT drive fan and turning vane
AWT Image No. 84: ED 697 01/NASA Glenn Research Center

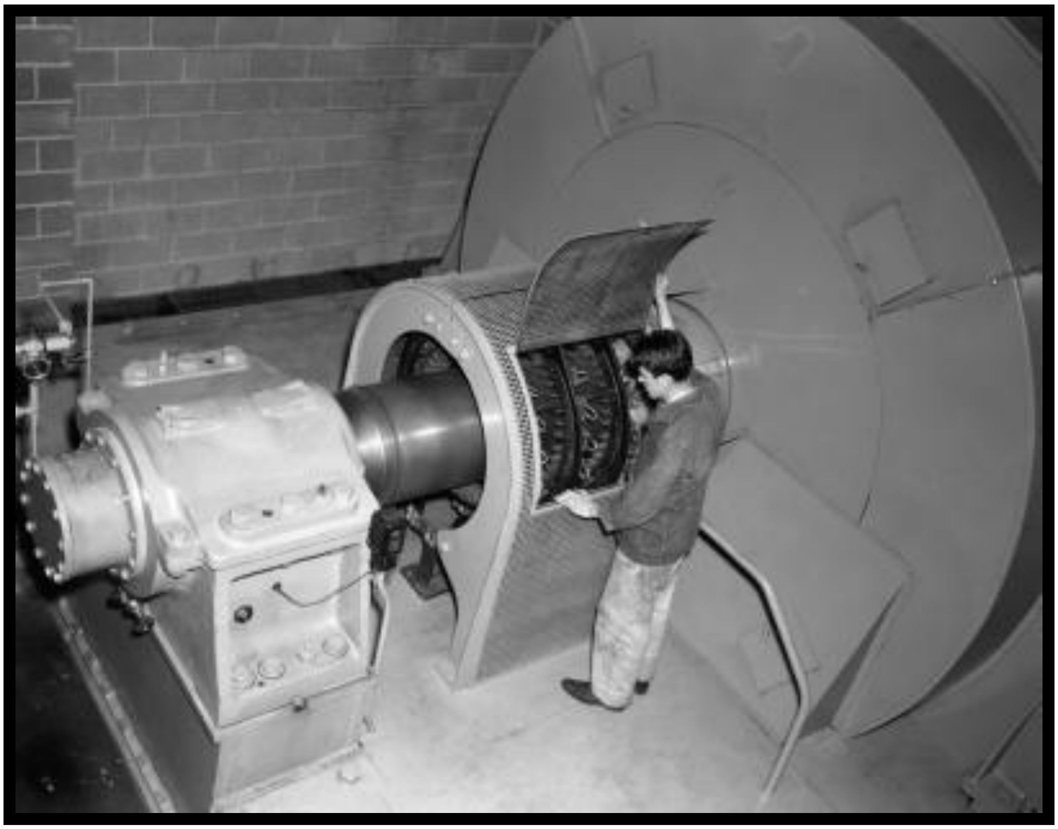
Original 31 foot diameter spruce wood fan being assembled in the Hangar for the AWT
AWT Image No. 85: 1943-01848/NASA Glenn Research Center (1943)

New blades being prepared in AWT shop area for installation in the tunnel
AWT Image No. 86: 1951-28240/NASA Glenn Research Center (1951)

As part of a large overall of the AWT in 1951, the fan blades, hub, and farings were replaced. The new farings were roughly twice their original size. The new 18-foot 8 ½-inch long nose faring was wider and extended upstream passed the bearing support. The new tail faring was 47 feet 10 1/8 inches long, but used the 30-foot 6-inch tip from the original faring. So the new tail extended over 78 feet down the southern leg of the tunnel.[142]

New fan hub being installed near the southeast corner of the AWT
AWT Image No. 87: 1951-28286/NASA Glenn Research Center *(1951)*

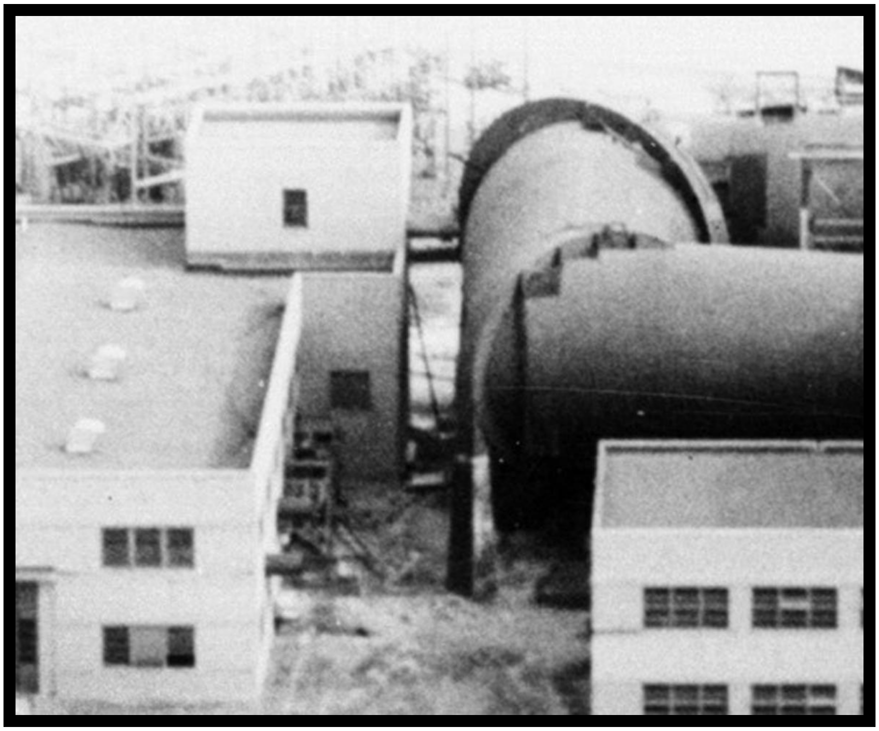
The fan was driven from 10 to 410 revolutions per minute by an 18,000-horsepower General Electric induction motor[1] that was located on the third level of the Exhauster Building's southeast corner.[143] The motor was supported by a "a modified Kramer system of speed control" which included a variable speed set, a constant speed set, and an amplidyne exciter set of generators located on the building's first floor.[144]



18,000-horsepower General Electric induction motor used to spin the AWT fan assembly
AWT Image No. 88: 1947-18325/NASA Glenn Research Tunnel (1947)

The drive shaft extension for the fan crossed the space between the Exhauster Building and the tunnel at an elevation of 28 feet 6 inches.[145] The shaft penetrated the tunnel 's southeast wall through the propeller hatch. The shaft was sealed at the hatch with flexible fittings to accommodate the tunnel shell's movement at different pressures and temperatures.[146] The shaft extended well into the tunnel, crossing through a panel of turning vanes before reaching the fan, faring, and supports.

[1] The drive motor and Exhauster Building are discussed further in the Support Buildings section of this document.

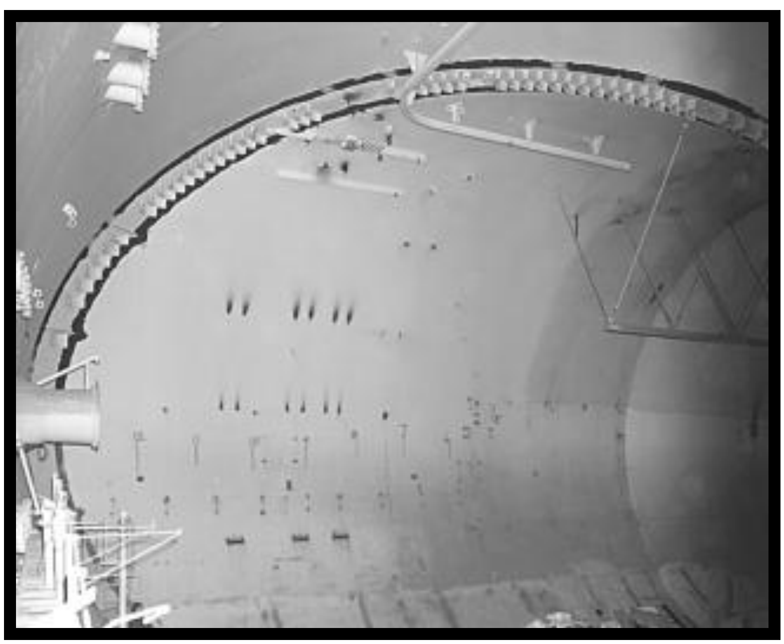


View from north of drive shaft extending from Exhauster Bldg. into southeast corner of AWT
AWT Image No.89: 1944-05064/NASA Glenn Research Center (1943)

View from east of drive shaft being installed at the propeller hatch on southeast corner of the AWT
AWT Image No. 90: 1947-17632/NASA Glenn Research Center (1947)

Panels of turning vanes were installed in each corner to guide the airflow around the corners and even it. These elliptical panels consisted of approximately 36 to 42 vertical vanes which were supported by three horizontal supports. The vanes were 2.5 feet long and half moon-shaped. The panel of vanes was affixed the curved corner rings of the tunnel. These corners had cement ramps that began wide on the tunnel floor then narrowed as they circled the interior of the tunnel. Each set of turning vanes had a moveable vane in the middle of the lower level to allow personnel to penetrate the device if needed.[147]

View from north of panel of turning vanes in the southeast corner of the AWT
AWT Image No. 91: 1944-03991/NASA Glenn Research Center (1944)



Fixtures which held a panel of turning vanes in the northwest corner of AWT
AWT Image No. 92: 2005-01620/NASA Glenn Research Center (2005)

Make-up Air: The tunnel's air supply system had to be constantly replenished since the exhaust scoop was removing air downstream from the test section. Cool dry air was introduced into the tunnel by the Make-Up Air System. Before adding air to the tunnel, a large air dryer[m] located outside the tunnel's southwest corner was used to remove condensation from the air to prevent shocks to the airflow. After being initially cooled in the primary coils, moisture in the air was absorbed in the dryer by activated alumina beds. The air temperature was reduced to final desired level with a second set of cooling coils.[148]

West facing view of the throat section and the primary make-up air line
AWT Image No. 93: 1951-27823/NASA Glenn Research Center (1951)

[m] See section on AWT Support buildings for description of Air Dryer Building.

This processed air was introduced into the tunnel through two portals in the western tunnel wall: a 48-inch diameter portal close to the air dryer and a 60-inch diameter aimed directly at the test section.[149]

By 1945, the extension of the 60-inch pipe directly into the engine's inlet had been implemented to increase the tunnel's capacity. In this way, higher pressure levels could be produced at the engine's inlet. This pressure differential over two between the engine inlet and nozzle produced higher altitudes.[150]

Make-up air line is shown extended into test section and attached directly to engine inlet
AWT Image No. 94: 1946-14244/NASA Glenn Research Center (1944)

It appears that the Make-Up Air line between the Air Dryer and the Refrigeration Building was to be removed in August 1985. A smaller diameter pump was instead run beneath the ground from this pipe to Icing Research Tunnel's vent tower. [151]

The two western sets of turning vanes and the Make-Up Air pipes were removed from the interior of the western end in 1959. The fan, drive shaft, farings, and turning vanes in the east end were removed from the eastern end in 1961. The fan's drive motor in the Exhauster Building still remains.

Exhaust Scoop: Because full-scale engines were operating in the tunnel, special efforts had to be undertaken to remove the engine's hot combustion products before they contaminated the tunnel's air stream. An exhaust scoop was located just beyond the test section to ventilate the tunnel. The designers estimated that this scoop would remove 40% of the engine exhaust, and that a 6000-pound-per-minute exchange of air would produce a 95% clean airflow.[152]

The scoop was a large airfoil-like vent aligned with the engine's exhaust. Originally this vented through the bottom of the tunnel into a pipe that split in two. One section ran northward to the Engine Research Building's compressors and the other to the east. The eastward pipe then split and entered the Exhauster Building through three ports in its western wall and connected to its compressors.[n]

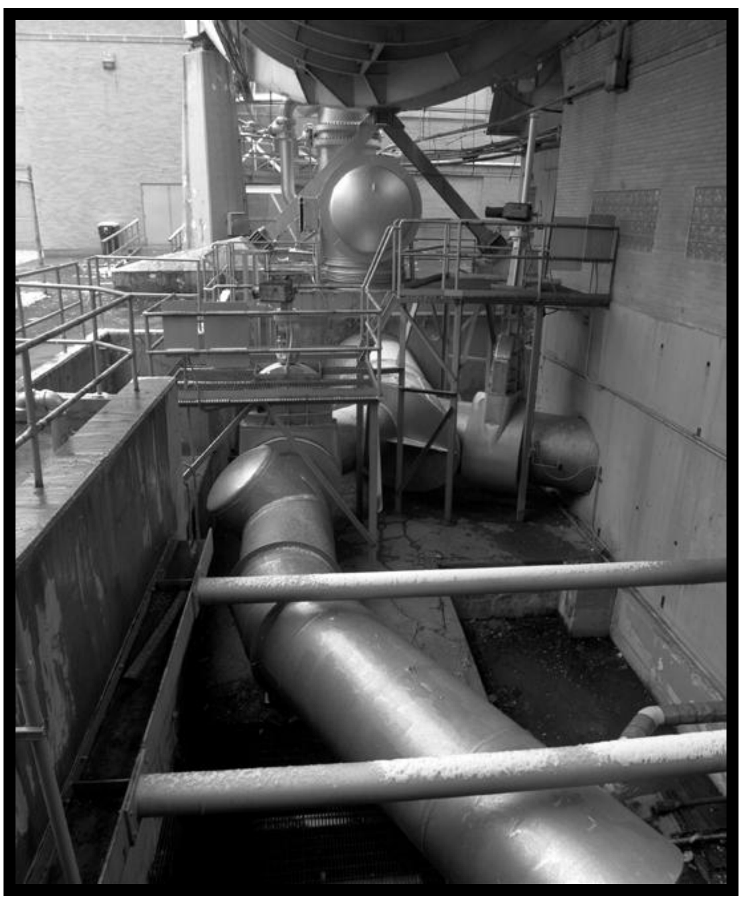
View east through test section with original exhaust scoop at far end just in front of the turning vanes
AWT Image No. 95: 1945-08982/NASA Glenn Research Center (1945)

[n] For description of Exhauster Building and its compressors see Support Buildings section of this report.

View from test section showing exhaust scoop downstream
AWT Image No. 96: 1945-08709/NASA Glenn Research Center (1945)

In 1951, a large exhaust-gas cooler was installed underneath this section of the tunnel. The scoop funneled the contaminated air out the bottom of the tunnel and through this 10 foot long and cooler. [153] A 72-inch diameter exhaust pipe extended from the back of the cooler. It traveled vertically for approximately 26 feet and through an expansion joint before splitting. One pipe turned horizontally through the Exhauster Building and into the new addition.[154] The other ran north across Ames Road and connected with the Engine Research Building's exhaust system at cell CE-22. Another branch of the line ran to the southwest and tied into the Small Supersonic Tunnels Building.[155]

View of the original exhaust scoop underneath the northeast section of the tunnel
AWT Image No. 97: 2007-02584/NASA Glenn Research Center (1951)

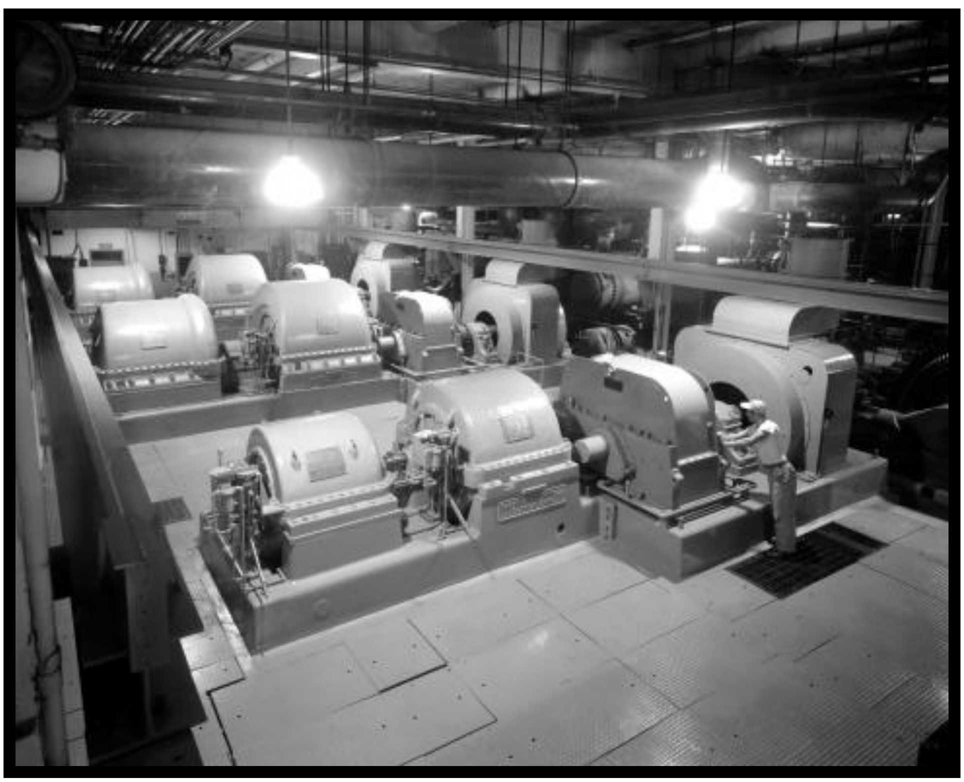


View from west of cooler pit under northeast section of AWT
AWT Image No. 98: 2007-00404/NASA Glenn Research Center (2007)

Altitude Simulation System:
The two primary aspects of altitude simulation are reducing the air pressure and lowering the temperature. This was accomplished through the Altitude Wind Tunnel's (AWT) large exhauster and refrigeration systems. These were vital components to the tunnel's operation and set it apart from other wind tunnels. The tunnel was originally designed for temperature altitude simulation of up to 30,000 feet and pressure altitude simulation of 45,000 feet.[156]

Exhauster System: In addition to removing contaminated air through the air scoop, the exhaust system was used to reduce the tunnel pressure to simulate altitude. The Exhauster Building directly to the east of the tunnel housed four 1750-horsepower reciprocating Worthington exhausters.[o] These pumped the tunnel air out through the exhaust scoop and expelled it into the atmosphere through 8 vent pipes.

The Exhauster Building pumps could originally only handle two thirds of the 6000 pounds of air per minute required by the AWT, so the system was complemented by the Roots-Connersville centrifugal compressors in the Engine Research Building's basement. This configuration originally could simulate pressure altitudes up to 45,000 feet. Most AWT tests were conducted over a range of altitudes beginning as low as 10,000 feet and increasing incrementally to 35,000 feet.



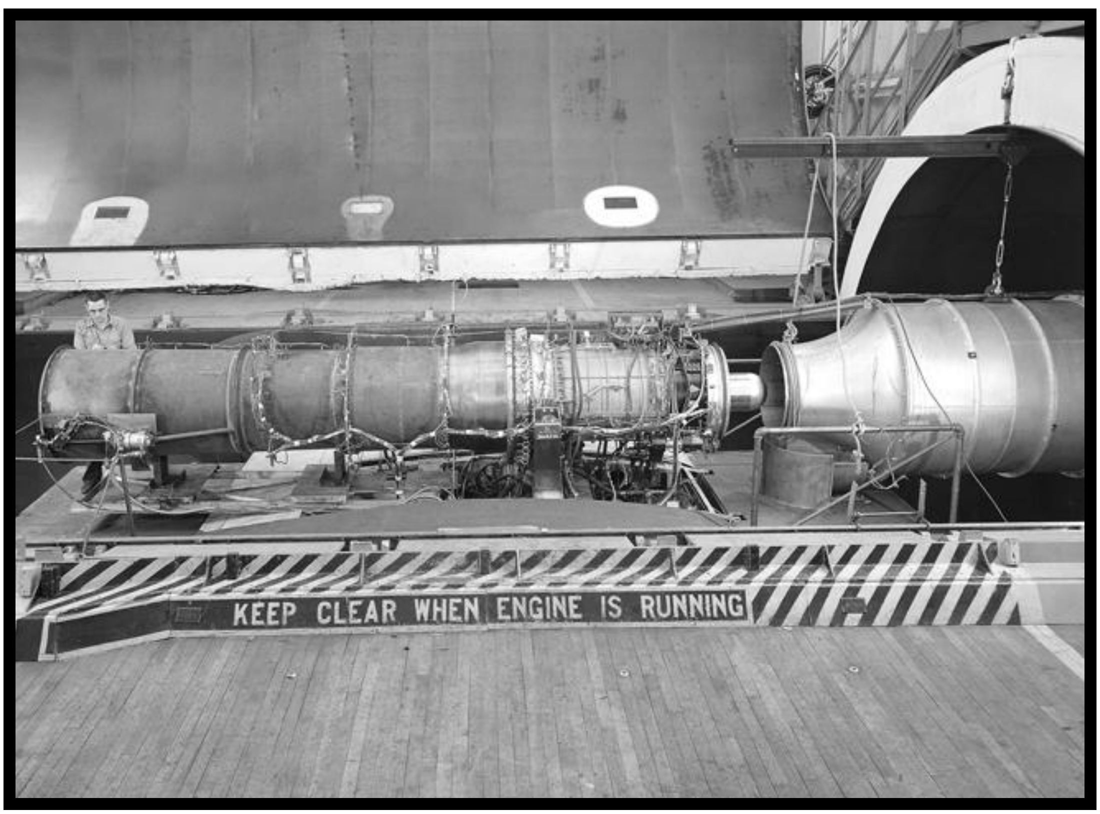
Roots-Connersville compressors in the Engine Research Bldg. supplemented the AWT's exhausters
AWT Image No.99: 1947-19605/NASA Glenn Research Center (1947)

[o] For description of the Exhauster Building and its compressors see the Support Buildings section of this report.

As part of a larger modernization program in 1951, the AWT's exhaust system was overhauled. The Exhauster Building was expanded with more powerful compressors, an exhaust gas cooler installed under the air scoop, and circulating water pump house built.

For the AWT's fuel system tests of the J65-B-3 engine in 1955, the exhaust scoop was not used. This resulted in the exhauster having to only make up for tunnel leakage, rather than leakage plus external airflow. [157] The use of an exhaust diffuser rather than a nozzle permitted the tunnel pressure to be almost the same as the turbine pressure. A couple of modifications allowed the engine to be tested at higher pressure levels up to 85,000 feet. [158]

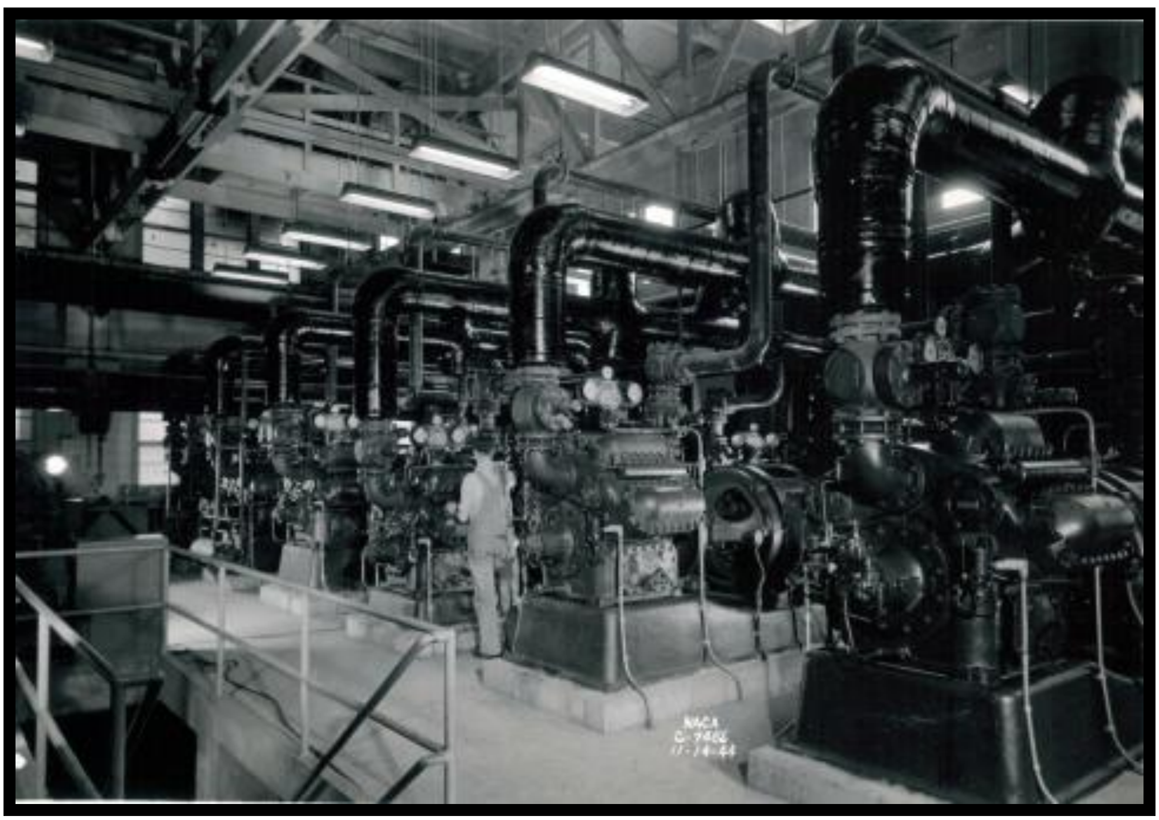
In 1957 the Propulsion System Laboratory's Central Air and Exhauster Building, which began operating in 1952 was linked to the exhaust system AWT and Engine Research Building systems. The result was an improvement of the AWT's pumping capacity from 12 to 7 pounds/second at 50,000 feet and 66 to 51 at 28,000 feet.[159]



J65-B-3 engine set-up that allowed the engine to be tested in the AWT at altitudes up to 85,000 feet
AWT Image No. 100: 1955-38289/NASA Glenn Research Center (1957)

Refrigeration System: The refrigeration system, which was largely contained in the auxiliary Refrigeration Building, could reduce the tunnel's temperature to -47 degrees Fahrenheit to create temperatures found at high altitudes. According to a 1944 *Aero Digest* article, "if used for ice-making, (the refrigeration unit) wound manufacture ten thousand tons of ice each twenty-four hours."[160]

The Refrigeration Building[p], directly to the west of the tunnel, contained fourteen 1500-horsepower Carrier centrifugal compressors and a flash cooler. The compressors converted the Freon 12 refrigerant into a liquid. The refrigerant was the pumped into the tunnel's 8 identical heat exchangers. These heat exchangers were a collection of 260 copper-plated coils arranged in a zig-zag design across the wide end of the tunnel. As the tunnel's air flow passed through the banks of coils, its heat was transferred the refrigerant. The refrigerant was then evacuated by four large vapor returns through flash cooler and distribution header and into the Carrier compressors' suction side. Here the heat was transferred to cooling water which was then pumped to the cooling tower where the heat was dissipated into the atmosphere. At its original capacity, 20,000 gallons of cooling water were required every minute of the cooling system's operation.[161]



View from northeast of Carrier centrifugal compressors inside the Refrigeration Building
AWT Image No. 101: 1944-7456/NASA Glenn Research Center
(1944)

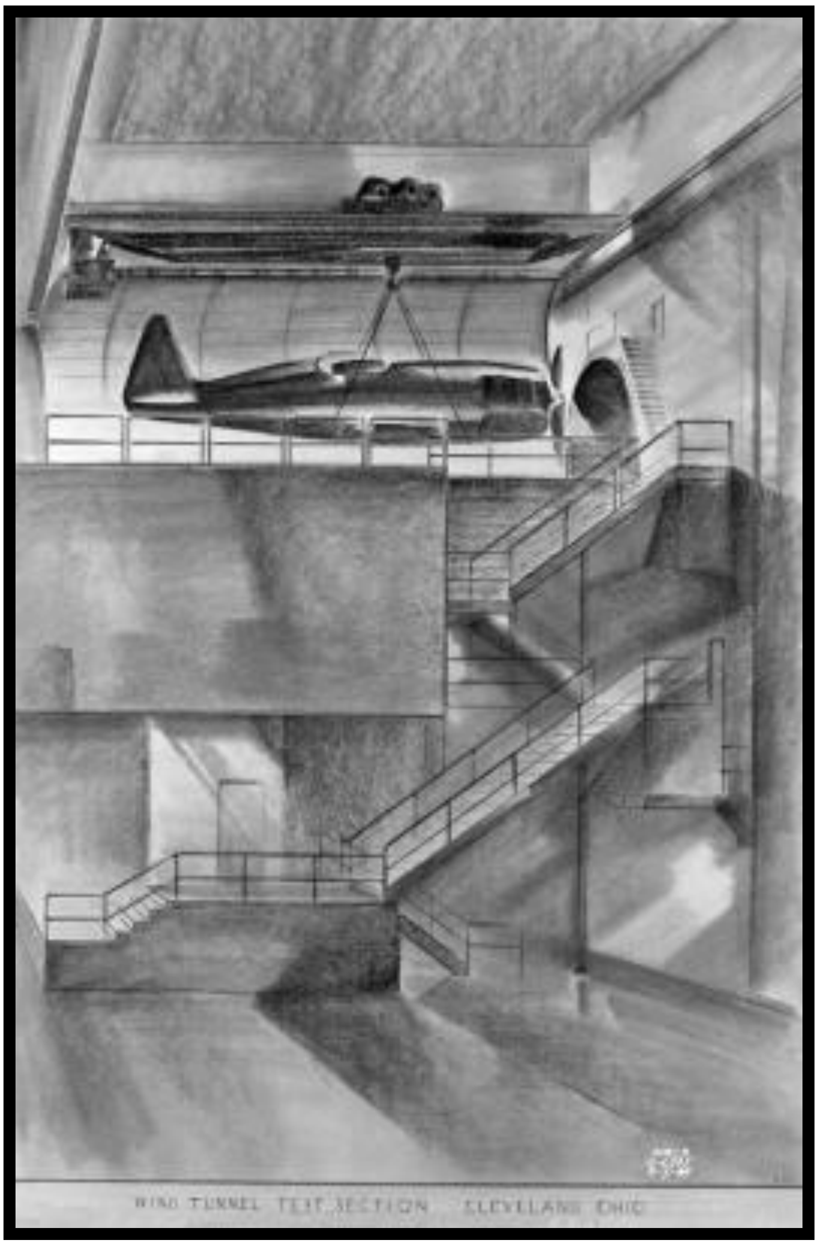
[p] For additional description of Refrigeration Building and system see Support Buildings section of this report.

A stair tower was located outside the western end of the tunnel, just outside of the Refrigeration Building. The stairs rose 5 flights from a cement base to a steel grated platform 41 feet 2 inches high. Each flight of stairs had a similar platform.[162] From these stairs provided access to the many refrigeration lines entering the tunnel.

Five of the 12-foot diameter refrigeration pipes that entered the west end of the tunnel extended into the interior at various distances. In late 1959, it was decided to cut these pipes off near the tunnel wall and plug them.[163] The Refrigeration Building and cooling system remain in use for the Icing Research Tunnel.

View from north of platform & cooling system pipes connecting the Refrigeration Bldg. (r) and the AWT (l)
AWT Image No. 102: 1950-25463/NASA Glenn Research Center (1950)

Test Chamber:
The Altitude Wind Tunnel's (AWT) test section was contained in the test chamber area in the rear section of the Shop and Office Building. The chamber had three floors—a ground level floor, a mezzanine, and an open two-story upper floor. Originally the first, underneath the tunnel, was not used. The second, to the side of the lower half of the tunnel, contained the Control Room, Fan Room, and manometers. The third, a high-bay area whose floor was even with the tunnel's midpoint, was used to load and install test articles in the test section. The tunnel entered from the west and exited to the right of this room on the second floor. The lower half of the tubular tunnel sat sunken between the second and third floors.



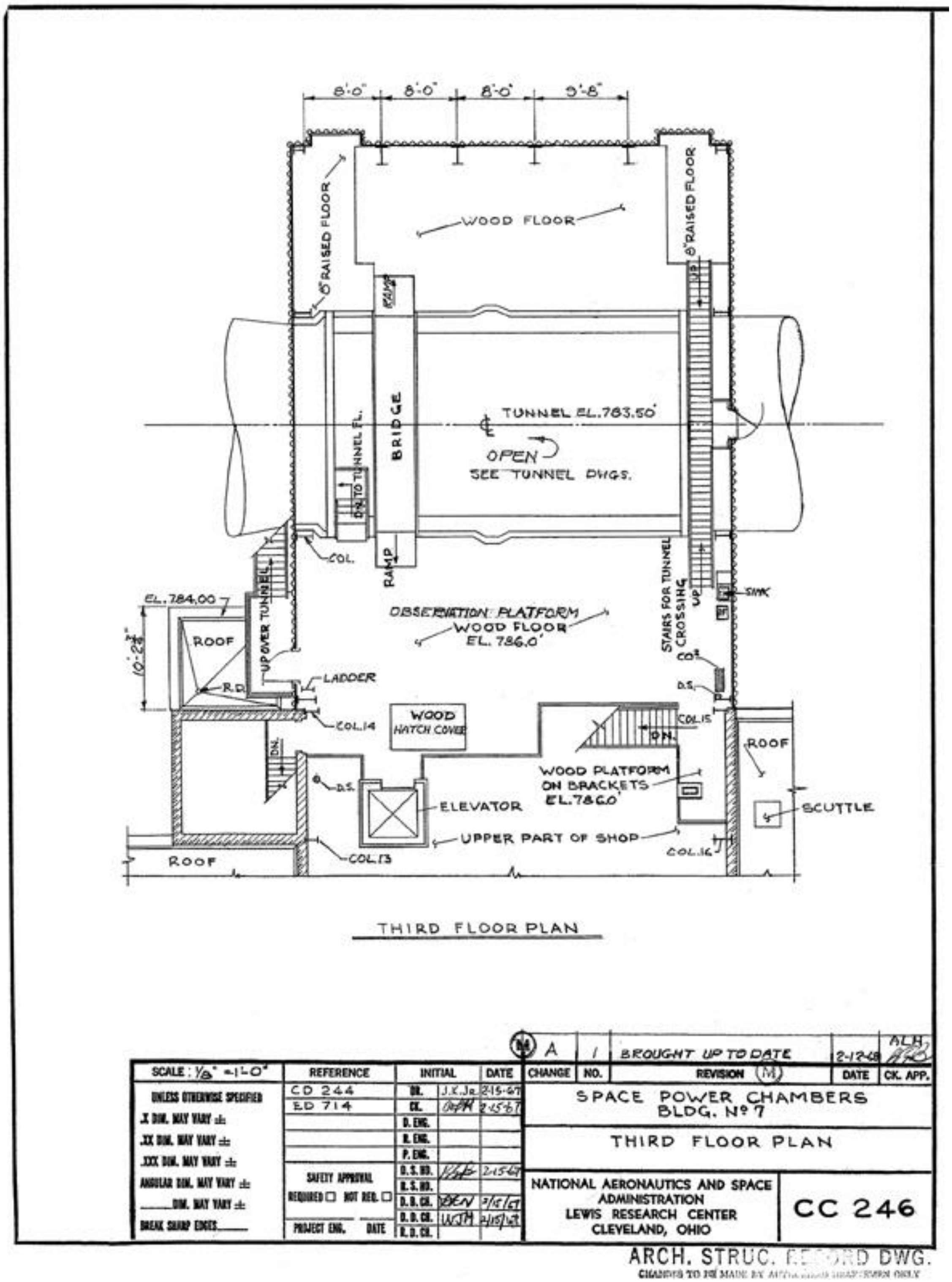
Drawing of three-level test chamber as seen from high-bay
AWT Image No. 103: 1944-06305/NASA Glenn Research Center (1944)

<u>Test Chamber Room:</u> The test chamber room on the upper level was a large open room approximately 52 feet high with three 12-pane square windows along top of the south wall, and three longer 36-paned windows along the top of the east and west walls. Entrance to this third floor was obtained from either the elevator or stairway, which are both located on the north end of the room where the test section wing meets the main portion of the Shop and Office Building.[164] There are pedestrian doorways on both the east and west walls leading to the tunnel roof.

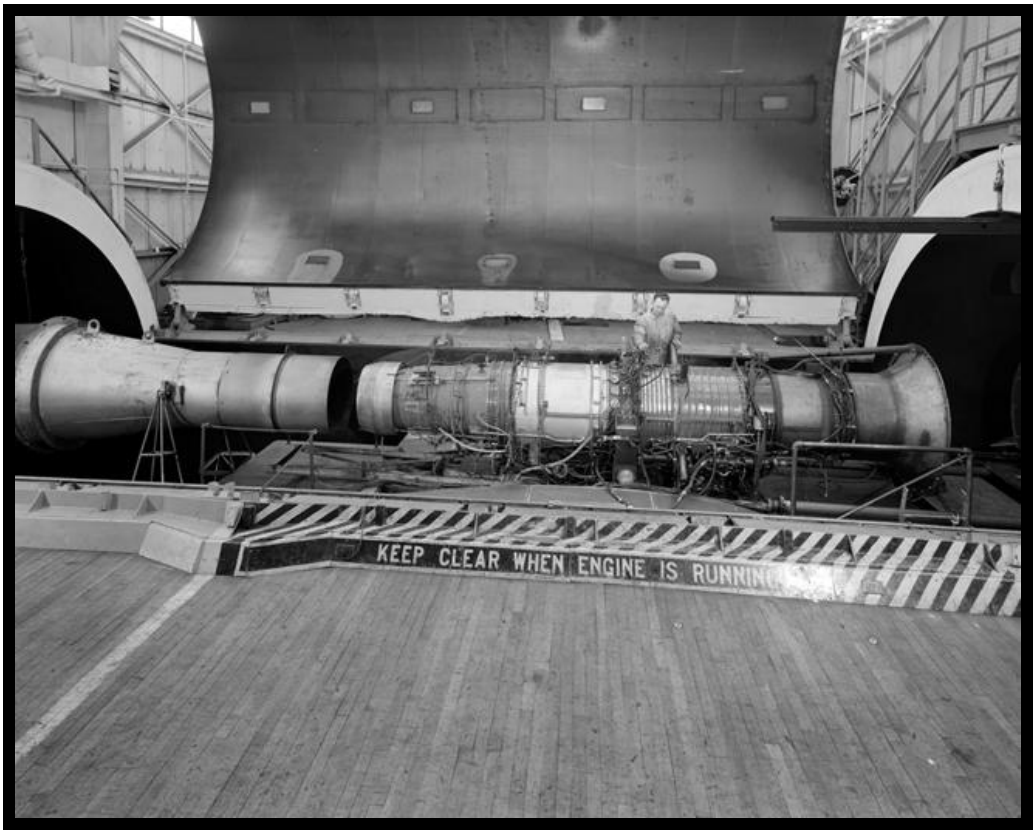
The test chamber room had a wooden floor on either side of the tunnel that was referred to as the observation platform. This floor is level with the vertical midpoint of the tunnel's test section. The wind tunnel entered from the west and exited to the east of this room. The upper half of the 20-foot diameter test section was a hinged lid that sealed near the floor level. The lower half was an open area between the observation platform and the mezzanine level. The test chamber is in the central high-bay portion of the Shop and Office Building. An overhead two-rail Shaw box crane runs north and south the length of the high-bay linking the test section to the shop area.

Along both the east and west walls are stairways that allow access over the tunnel. The steel stairs rise approximately 10 feet 6 inches above the floor to an 8-foot long landing with another identical stairway leading down the opposite end of the landing. A door at the landing permitted access to the exterior of the tunnel outside of the building. [165] After the tunnel's lid was permanently removed in the early-1960s, a horizontal foot bridge was installed over east end of the test section. This bridge was installed prior to 1967.

View from east of test chamber with stairwell over test section in background
Image No. 104: 1951-28464/NASA Glenn Research Center *(1951)*



Drawing showing test chamber room after conversion to SPC
AWT Image No. 105: CC 246 01/NASA Glenn Research Center



View from south of observation platform, test section, and lid in the test chamber room
AWT Image No. 106: 1955-40572/NASA Glenn Research Center *(1955)*

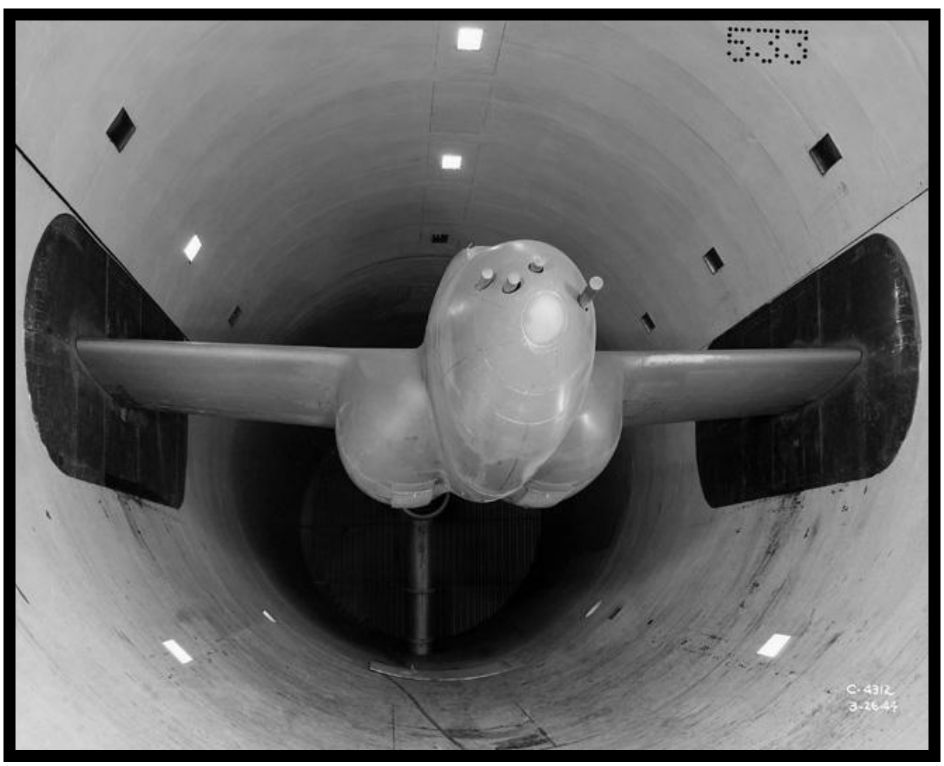
View of the AWT test chamber room from west as it appears in 2007
AWT Image No. 107: 2007-00403/NASA Glenn Research Center *(2007)*

<u>Test Section:</u> The Altitude Wind Tunnel test articles and models were installed and studied in the 20-foot diameter, 40-foot long test section. It was the narrowest portion of the tunnel and had the highest speeds. Its size was driven by the NACA's initial desire to run full-scale 3000-horsepower reciprocating engines with propellers. The section was large enough to fit entire fuselages of early jet aircraft and a B29 bomber's Wright R-3350 engine with its propeller. [166]

Originally access to the interior of the test section was afforded by a doorway in the bottom of the east end of the test section. This door opened to a stairwell that led to the mezzanine level of the balance chamber.[167] Later, after the tunnel ceased operations, a metal staircase permitted access from the east side of the observation platform. The lower half of the test section contained four small observation windows, two on the north side and two on the south.

The AWT test section was designed to be large enough to operate large reciprocating engines
AWT Image No. 108: 1949-23957/NASA Glenn Research Center (1949)

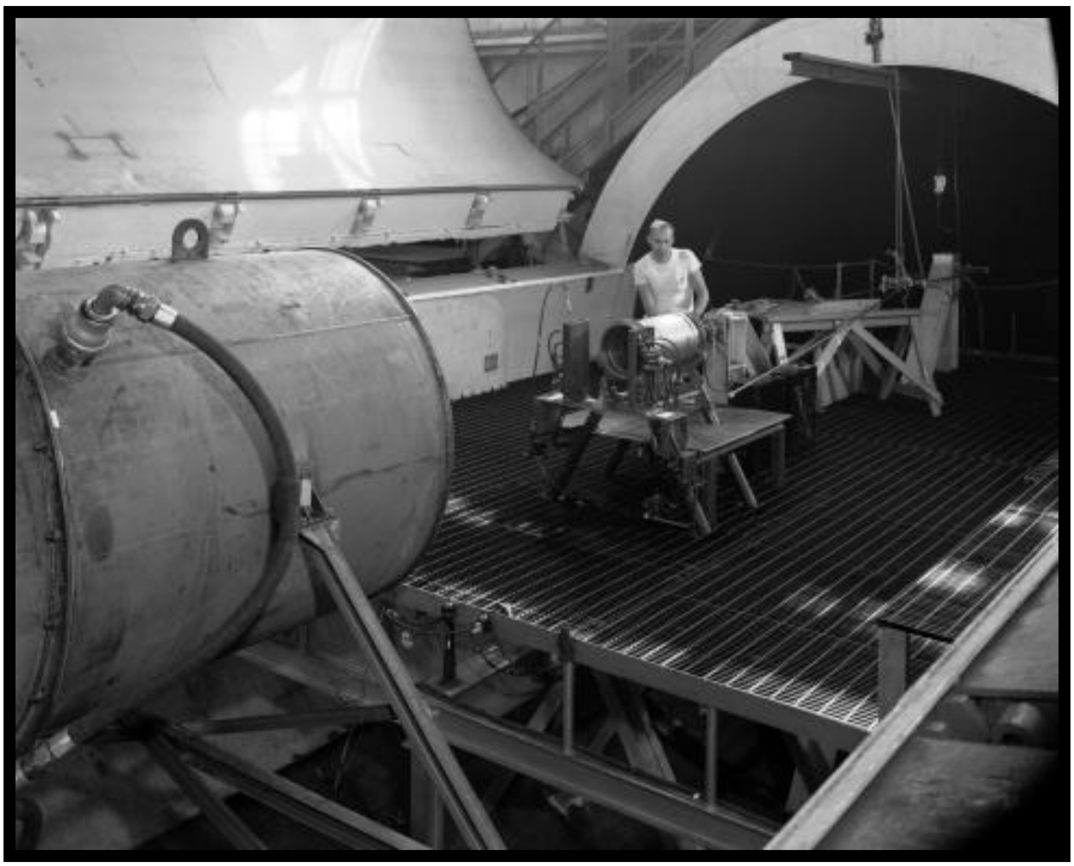
A technician enters the AWT test section through a doorway in the floor
AWT Image No. 109: 1949-23125/NASA Glenn Research Center (1949)



Although not anticipated initially, the test section was large enough to test entire jet aircraft
AWT Image No. 110: 1944-04312/NASA Glenn Research Center (1944)

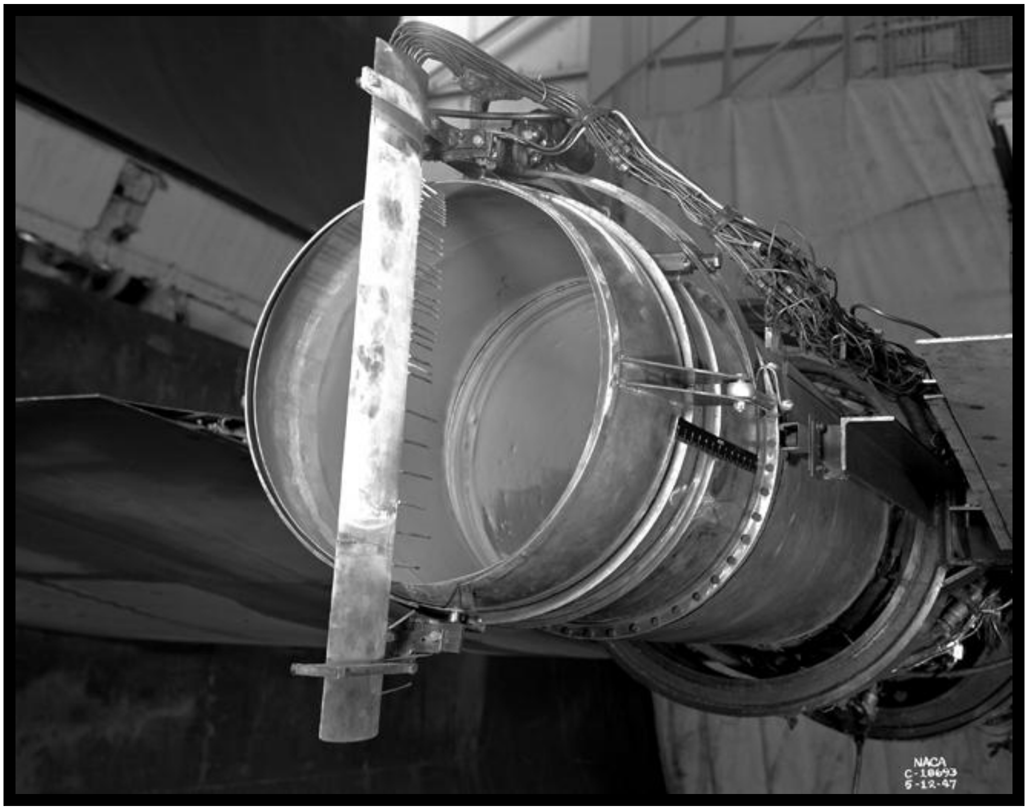
Engines tested in the AWT were incorporated onto aircraft fuselages or to nacelles on sawed-off wing sections created specifically for the test. In either case, the wing or wings stretched across the test section to permanent pins, or trunnions, on the tunnel walls. These moveable trunnions allowed the angle of attack to be adjusted.[168] A strut mounted vertically on the tunnel floor was often used for additional support. Originally there were also three support stands that could be mounted to the bottom of the test section.[169]

In the 1950s it appears the same wing span was used to support a number of different jet engines. For a 1957 series of nozzle tests on the Pratt & Whitney J57, the engine was fixed to a stand mounted vertically to the test section floor. For several rocket tests in the late 1950s, a grated metal floor was installed approximately 7 feet above the bottom of the test section. This platform allowed personnel to work at the level of the test article while setting up tests.



A metal platform was installed in the test section for several rocket tests in the late 1950s
AWT Image No. 111: 1958-48163/NASA Glenn Research Center (1958)

A survey rake was designed on an approximately 36-inch by 4 ¼-inch arm that could be rotated into the nozzle outlet of engines being tested. This arm had a row of 2 to 3-inch instrumented tubes that measured total pressure, static pressure, and other thermocouples.[170] In addition, the scale system of the balance frame measured thrust, drag, lift, and pitching movements of the test article.[171]

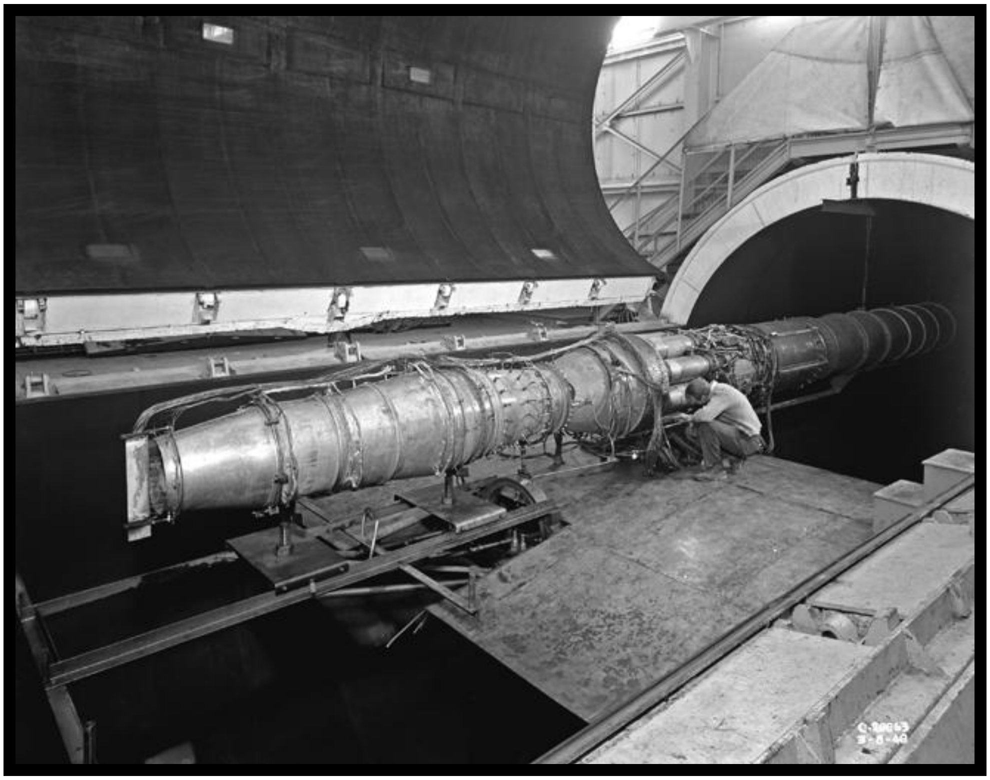


Survey rake installed over exhaust pipe of Westinghouse 24C engine
AWT Image No. 112: 1947-18693/NASA Glenn Research Center *(1947)*

Lid: During its operational period, the tunnel had a hinged lid the was operated by a motor-driven system with large counterweights, pulleys, and cables to open, close, and lock the door into place. [172] The rear of the lid had a two large hinges 2 feet 7 ¼ inches above the floor level that allowed the lid to be opened. [173]

A motorized drive shaft, elevated on stands 10 feet above the observation platform, ran nearly the entire width of the room along the south wall. On each end of the shaft was a drum that fed wire rope over pulleys that hung from a beam along the ceiling and down to a flange on top of the test section lid. The 24-inch diameter pulleys, which were 26 feet above the floor, lifted the curved lid to allow access to the interior of the test section.[174] The lid could be opened in approximately 10 minutes.[175]

The test section clamshell lid was 40 feet long, 20 feet wide and 10 feet high. It was segmented into seven sections by steel ribs. Approximately 4 feet above the floor on each of these ribs was an 18-inch diameter hand-wheel that was used to lock the lid once it was lowered in place. Each of these sections contained an observation window. The second, fourth, and sixth section had 3 foot ½ inch rectangular viewing windows on the latch side of the lid. The first, third, fifth, and seventh had these windows on top of the lid. In addition, a periscope camera could be inserted through the top of the lid to view ramjet and afterburner combustion flames.[176]



View from northeast of AWT test section with its clamshell lid raised
AWT Image No. 113: 1948-20863/NASA Glenn Research Center (1948)

A group of officials on the viewing platform. The test section lid is closed to the right.
AWT Image No. 114: 1944-07498/NASA Glenn Research Center (1951)

Balance Frame: An intricate steel web, called the balance frame, supported the trunions from below the test section. In this way the trunions and test article were independent from the tunnel shell. A lever and scale system bears the balance frame so that all forces and movements of the test article are measured.[177] This steel cage extended outside the building and was attached to the concrete pylons with flexible jacks. [178]

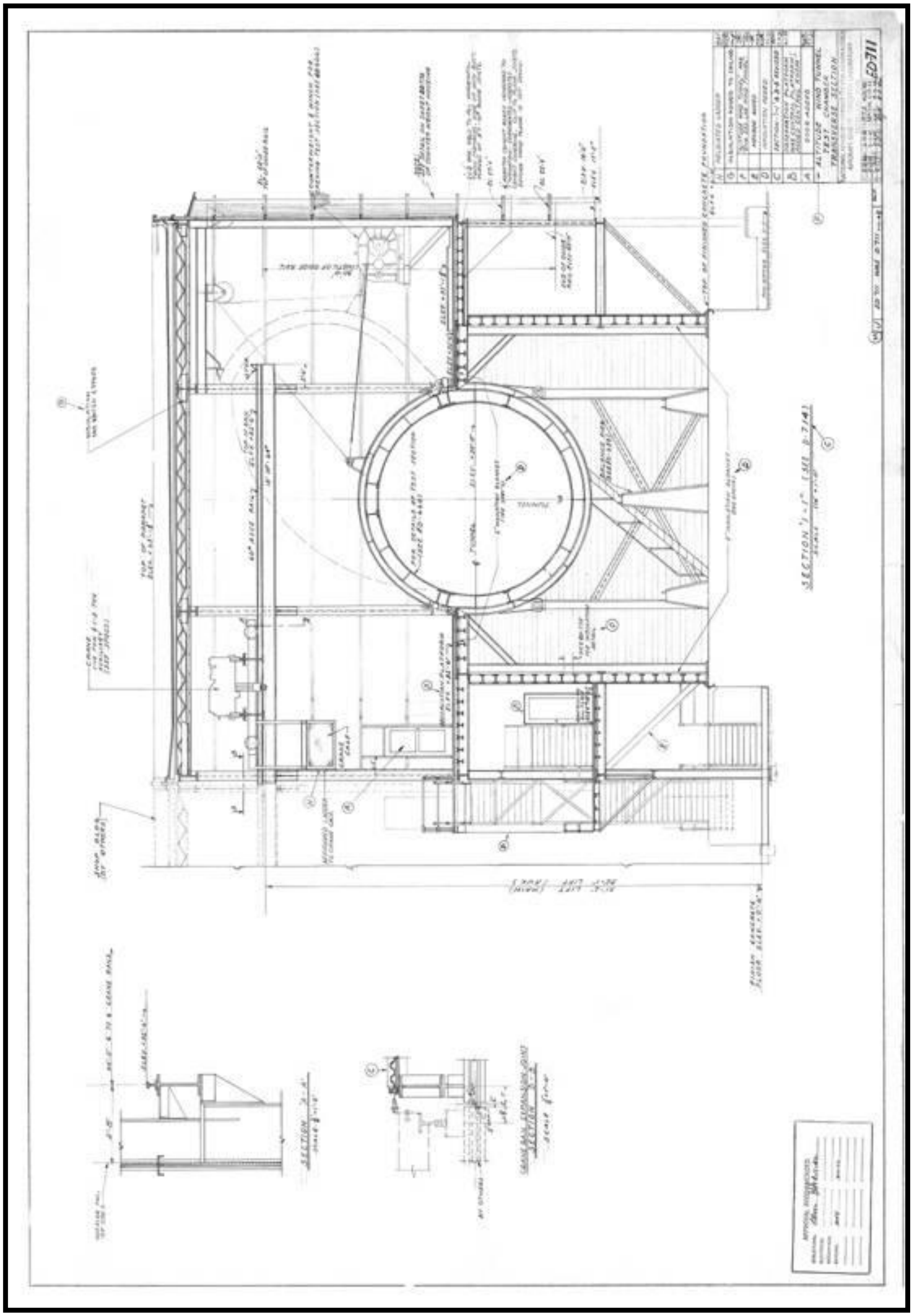
The engines were mounted on wing spans test section. The wing tips were attached to the balance frame's primary trunions which mechanically could measure the pitch of the test article. The balance frame contained 6 scales which recorded the various forces on the engine.[179] The test section also had a 28-inch diameter circular trunion with an approximately 4-inch tapering extension.[180]

Toledo scales and balance frame underneath the AWT test section
AWT Image No. 115: 1945-09635/NASA Glenn Research Center *(1945)*

The test section portion of the tunnel was elevated 12 feet 11 7/8 inches above ground level. This was supported by two 24 foot 11 inch vertical steel beams on each side of the tunnel, one 22 foot ¼ inch beam across the bottom, and two 12 foot diagonal beams going from the outer beams to a midpoint on the ground. This whole structure was on a steel base on the ground.[181]

The four sets of test chamber balance piers were of different shapes depending on their location. They ranged from 4 feet 7 inches wide to 9 feet 7 inches wide. Beveled steel caps were attached to the piers, and the tunnel's rollers and supports were attached onto those. The largest piers were 21 feet ¼ inch tall. Others were roughly between 4 and 9 feet in height. Steel braces ran the length of the piers and 2 ½ to 3 feet into the ground.[182]

View from northwest of balance chamber piers visible from outside the test chamber
AWT Image No. 116: 2005-01469/NASA Glenn Research Center (2005)



Cross section drawing showing test section and balance frame
AWT Image No. 117: ED 711 01/NASA Glenn Research Center

Control Room: The 16 ¾-inch by 10 foot 3 ¾ inch???? soundproof control room was located on the mezzanine level below the observation platform. [183] In the control room, the operator could control all aspects of the tunnel—pressure, temperature, air speed, angle of attack, and engine operation. The operators worked with assistants in the Exhauster Building and Refrigeration Building.[184]

The control room and test section were housed in an air-tight balance chamber which kept both areas at the same pressure level. This allowed the instrumentation lines to enter the test section without pressure fittings or hermetically sealed penetrations. Access to the balance chamber was provided by an airlock on the mezzanine level.

Main console in the AWT control room which was used control the engine in the test section
AWT Image No. 118: 1945-13099/NASA Glenn Research Center *(1945)*

There were two sets of instrumentation panels along the sides of the room. Although the configuration of the panels changed frequently, the principal wall contained the primary make-up air, drive fan, and engine controls. The other wall controlled the combustion, refrigerated, and cooling air, and the exhausters.

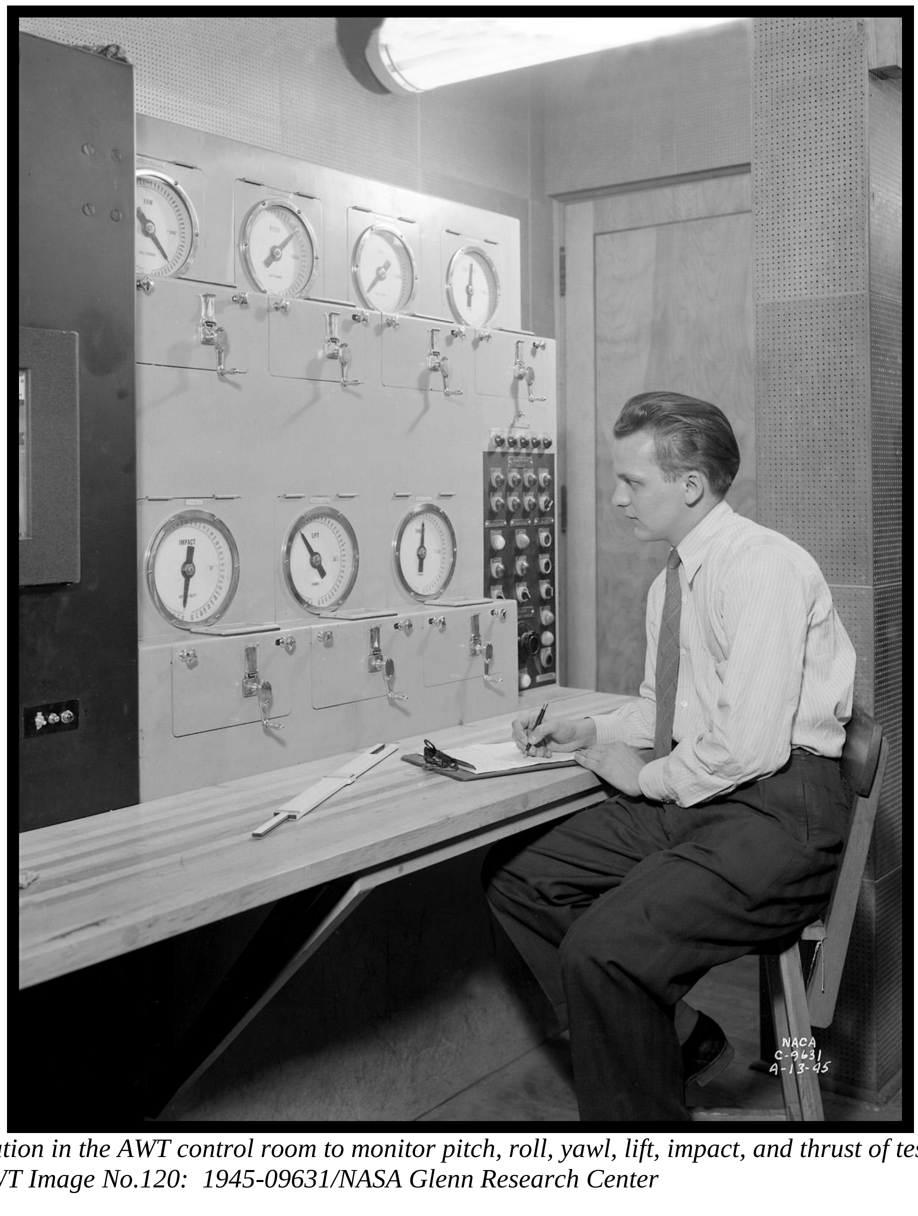
The north panels had two 2 foot 7 inch high and 20-inch wide maple desks in front of them. The first to the left was 12 feet 7 ¼ inches long with two 14 ¾ inch by 9 ½ inch rectangular portals for engine control levers.[185] The first of the three workstations monitored the Make-Up Air System. It included indicators for Ingersoll-Rand exhausters, the Engine Research Building system, and air heaters. The next station included the drive motor and fan controls. It also included balance chamber indicator lights.

Original AWT control room with the engine operation panel and controls
AWT Image No. 119: 1945-09629/NASA Glenn Research Center *(1945)*

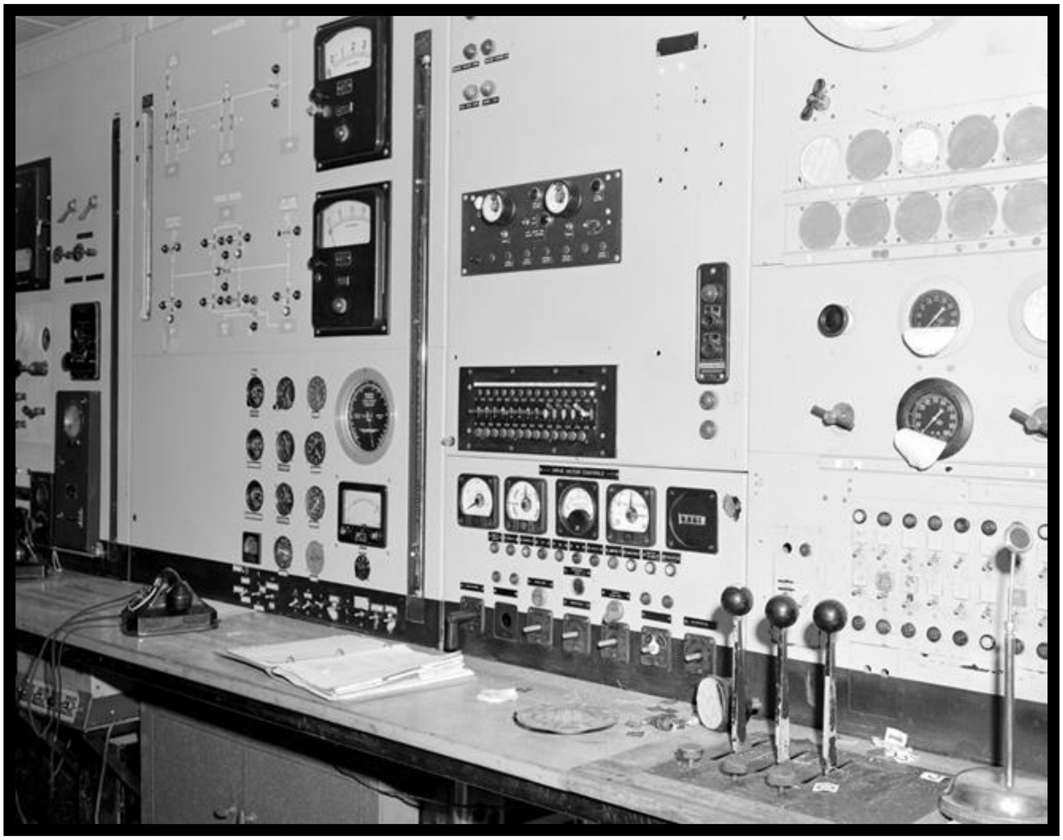
The third station was used to control the engine being tested. The intercom microphone, log book, and test run sheets were located here. It also included two sets of three control levers that went through the desk into a pneumatic system that operated different facets of the engine. The panel contained the master air speed, altitude, and temperature gauges. It also contained a plethora of pressure, temperature, and airflow from different locations in the test article. It also included gauges for engine oil, clutch, fuel flow, and other engine behavior.

An indicator light would be illuminated when the balance frame scale was in balance. The operator could press a control button to obtain printout tapes of the force scale readings.[186]

The second desk along the same wall was 8 feet ¾ inches long and had two stations. [187] The first contained several graphs and gauges. The second station contained impact, thrust, lift, pitch, roll, and yawl gauges. Between the two desks were three approximately 24 inch manometers labeled "Control Room Fuel" mounted to the panel.



Station in the AWT control room to monitor pitch, roll, yawl, lift, impact, and thrust of test article
AWT Image No.120: 1945-09631/NASA Glenn Research Center (1945)



AWT control room as it looked after 1951 modifications
AWT Image No. 121: 1952-30418/NASA Glenn Research Center (1945)

The other wall of control panels did not have desks in front of them. The first panel was comprised of controls and gauges for the four exhauster pumps. The next had the cooling air controls and gauges. The third contained the controls and indicators for the fourteen Carrier units in the Refrigeration Building. The fourth had the combustion air gauges.

The panels were 7-foot 7-inch squares. The upper panel portion was 5 ½ inches thick while the lower base section below the desk was 9 ½ inches thick. The control panels were supported by steel supports and wall vibration isolators braced the structure against the wall.[188]

The control room was modified around 1951. The panels were either painted white or replaced. It appears that many of the engine monitoring gauges were removed. This room was later expanded during the Space Power Chamber years, but a new control room for the chambers was created underneath the test section.

Eventually the original control room was cannibalized, gutted, and converted into a storage area. Only the acoustical tiles, a couple of wall-mounted gauges, and some original cabinets remain.

Former AWT control room gutted and being used for storage in 2007
AWT Image No. 122: 2007-00399/NASA Glenn Research Center (2007)

Former AWT control as it appeared in 2007
Image No. 123: 2007-0398/NASA Glenn Research Center (2007)

Index of Altitude Wind Tunnel Photographs

SPACE POWER CHAMBERS
(Microwave System Lab—Building 7)
NASA Glenn Research Center at Lewis Field
Cleveland
Cuyahoga County
Ohio

Historical & Architectural Information:
Space Power Chambers
1959-75

WRITTEN HISTORICAL AND DESCRIPTIVE DATA
PHOTOGRAPHS

Bob Arrighi
Wyle Systems, Inc.
NASA Glenn History Program

January 2009

SPC Section Contents

Part I: Historical Information

The Space Power Chambers with chamber No. 1 to left and chamber No. 2 occupying rest of tunnel
SPC Image No. 1: 2005-01492\NASA Glenn Research Center (2005)

View of NASA Lewis Research Center from the northwest with the SPC left of center
SPC Image No. 2: 1963-066570/NASA Glenn Research Center (1963)

SPACE POWER CHAMBERS
(Microwave Systems Laboratory)

Location: National Aeronautics and Space Administration (NASA)
John H. Glenn Research Center at Lewis Field
21000 Brookpark Road
Cleveland, Cuyahoga County, Ohio

The Space Power Chambers (SPC) facility is located in the wedge-shaped block of Ames, Moffett, Durand, and Taylor roads near the center of the Glenn Research Center. The facility faces north on Ames Road with the Space Power Chamber No. 1 to the east and Space Power Chamber No. 2 wrapping from the northwest corner past the southwest corner and through the south leg.

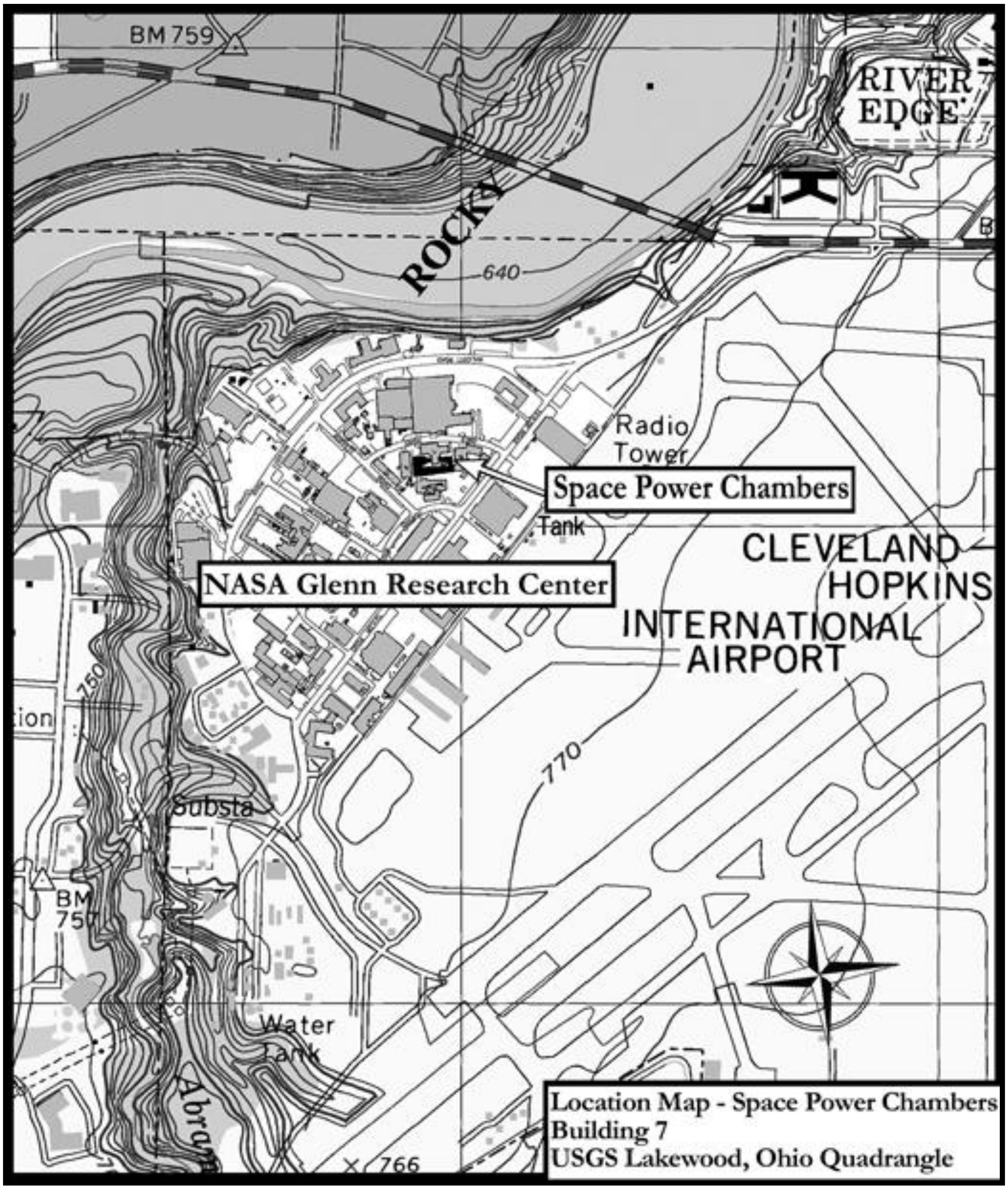
Elevations: Space Power Chamber No. 1's southeast corner was 754 feet, northeast corner 755 feet. Space Power Chamber No. 2's southwest corner was 751 feet, south leg 755 feet, and northwest corner 752 and 735 feet. The Shop and Office Building was at 754 feet, Refrigeration Building 754 feet, Cooling Tower No. 1 752 feet, Air Dryer Building 753 feet, substation 757 feet, Steam Plant 759 feet.[189]

UTM Coordinates: 17 427938E 4585154N (NAD83)
Latitude: 41.41471, Longitude: -81.86227
Quadrangle: Lakewood, Ohio

Present Owner: NASA John H. Glenn Research Center at Lewis Field.

Present Use: The SPC's two test chambers were demolished in 2009. The SPC was last used for its original function in 1975. The former Shop and Office Building, presently named the Microwave Systems Laboratory, was not part of the demolition. The shop and high-bay areas house the Near Field and Far Field test facilities. These test ranges are used by the Communications Division for antenna testing and vehicle and equipment storage. The office portion of the building is used primarily as office space by the Educational Programs Office.

The former wind tunnel test section was recently used for storage of large pieces of equipment for the Communications Division. The surrounding room was littered with excess equipment and supplies. The former SPC No. 1 control room in the balance chamber below the test section is now used as the Far Field Antenna Test Facility. The overhead crane remains in working condition and is used by the Microwave Systems Laboratory.



SPC Image No. 3: Regional Map, Space Power Chambers, NASA Glenn Research Center

<u>Original Plans:</u> As the Altitude Wind Tunnel (AWT), the facility served as an altitude simulating engine research wind tunnel from 1944 to 1958. The AWT was the first and largest wind tunnel at the laboratory. The addition of large supersonic wind tunnels and altitude simulating engine test stands at the lab between 1948 and 1955, however, reduced the need for the tunnel.

During the rush of the early space era, the tunnel was used for several small rocket engine tests. In 1959 and 1960, the interior of the tunnel was used for a series of Project Mercury tests. Two sets of turning vanes, the cooling coils, and make-up air valves were removed at that time, ending the facility's days as a wind tunnel.

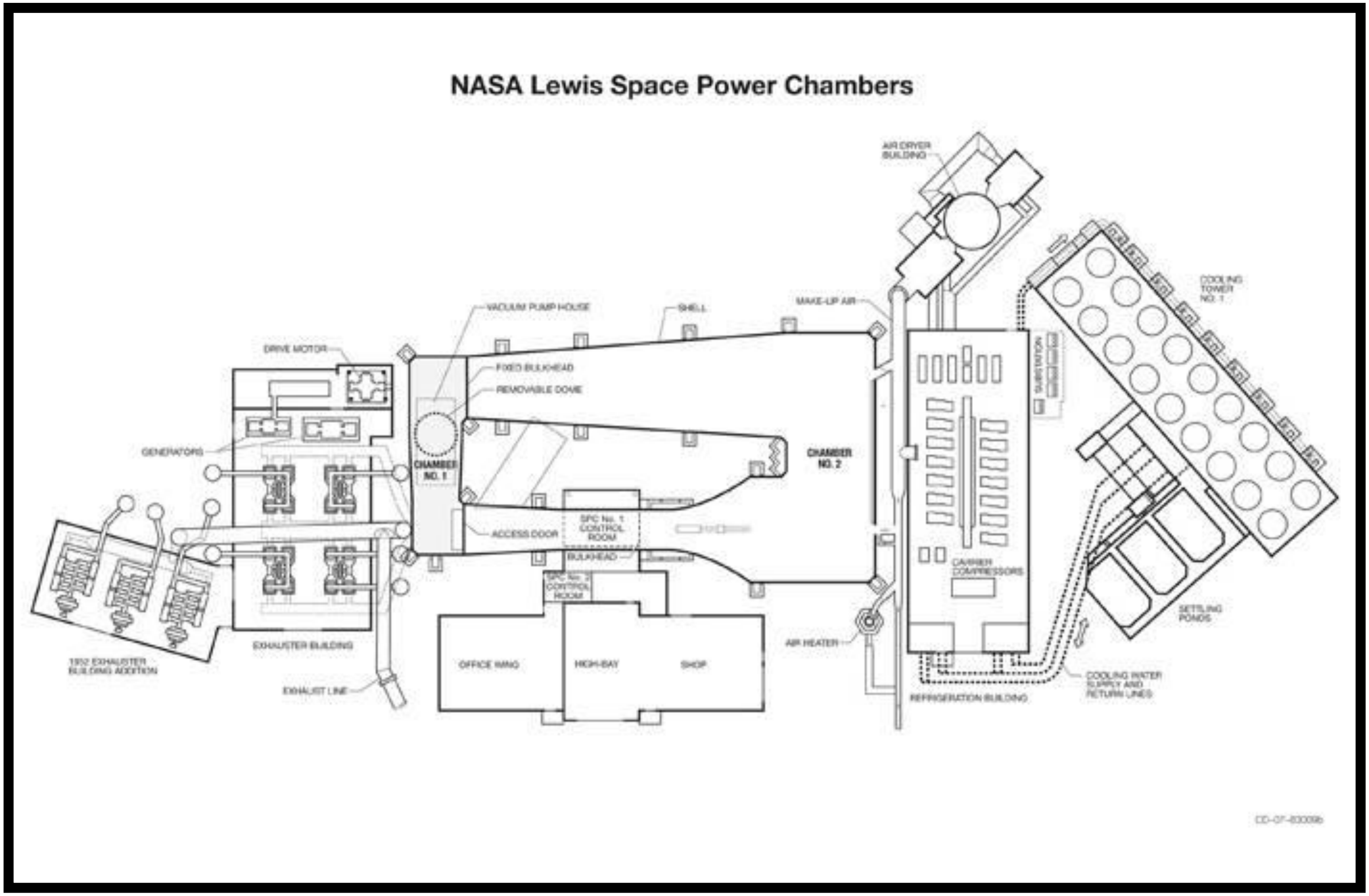
Between 1961 and 1963 the facility was converted into two large test chambers and renamed the Space Power Chambers (SPC). The drive fan, exhaust scoop, and turning vanes were removed from the east end of the tunnel and bulkheads were inserted to create the two chambers. The high-vacuum chamber, SPC No. 1, was located in the eastern leg of the former wind tunnel. A dome with a removable lid was added near the southeast corner. A high altitude chamber, SPC No. 2, occupied the entire south leg, the west leg, and the throat section of the former tunnel. The SPC was used for various tests of the Centaur second-stage rocket until the mid-1970s.

The Shop and Office Building (Building 7) is a T-shaped structure facing north on Ames Road. The Shop and Office Building contained the former tunnel test chamber and the SPC control rooms in its south extension, two floors of offices in the east wing, a shop area in the west wing, and a high-bay area with an overhead crane running north and south down the middle of the building to transport articles into the test section. The test chamber room in the rear was an open two story space with the tunnel sunken in the floor.

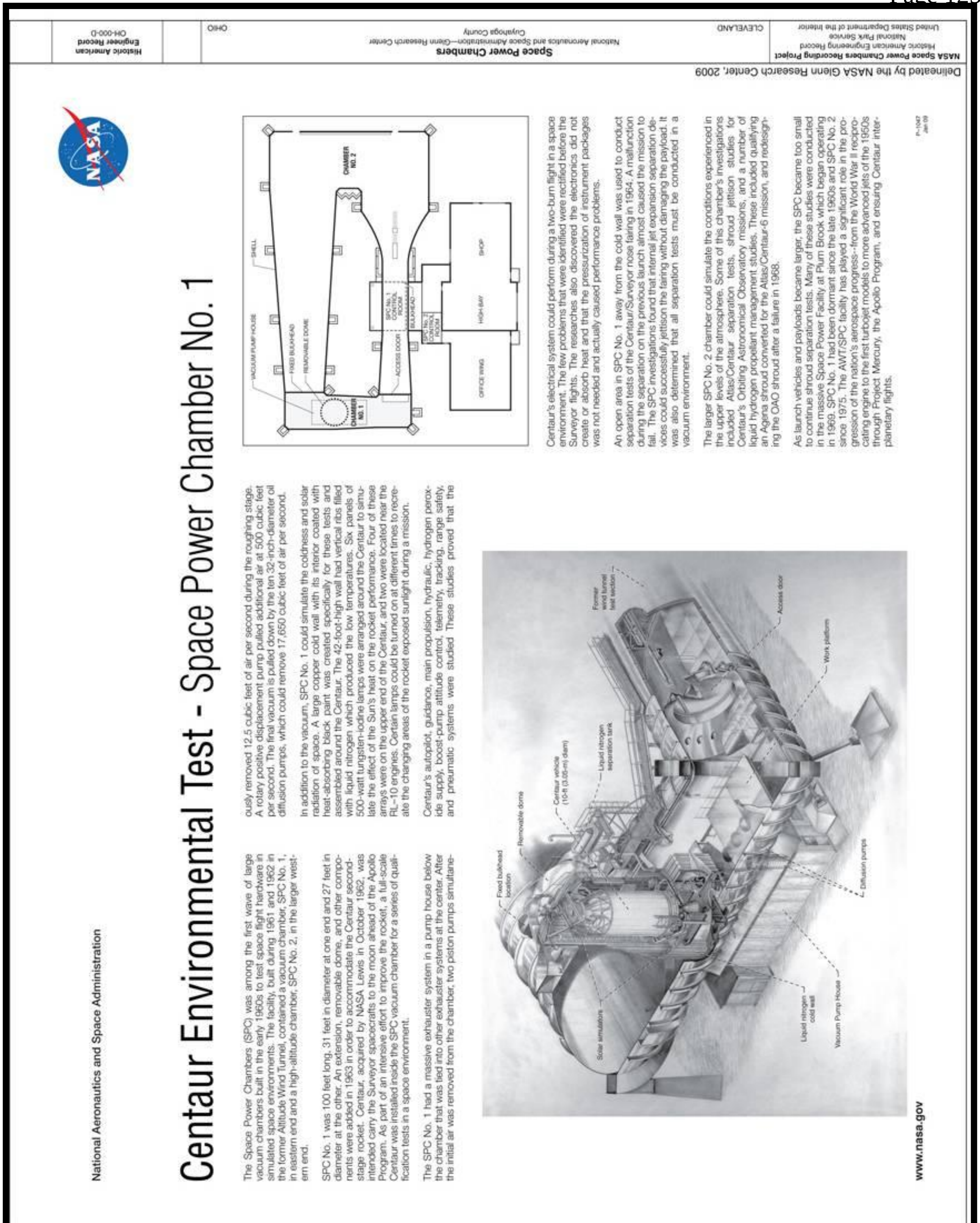
The Exhauster Building (Building 8, currently the Visitor Information Center) is a two-story rectangular structure located immediately to the east of the wind tunnel. A section of the building was used as a clean room during the 1960s and renamed the Solar Power Laboratory. The Refrigeration Building (Building 9) is a rectangular structure located to the immediate west of the tunnel. It contains cooling equipment for the AWT and Icing Research Tunnel. Other related buildings include Cooling Tower No. 1 (Building 10), the Vacuum Pump House, and the Circulating Water Pump House (Building 78, renamed the Solar Power Lab Annex).

SPC with Shop & Office Bldg (c), Solar Power Lab (l), Refrigeration Bldg. (r)
SPC Image No. 4: 1979-04019/NASA Glenn Research Center (1979)

Interior of SPC No. 1 in 2005
SPC Image No. 5: 2005-01479/NASA Glenn Research Center (2005)



Drawing of the Space Power Chambers complex with SPC No. 1 to the left and SPC No. 2 to the right
SPC Image No. 6: CD07 83009b SPC/NASA Glenn Research Center (2007)



National Aeronautics and Space Administration

Centaur Environmental Test - Space Power Chamber No. 1

The Space Power Chambers (SPC) was among the first wave of large vacuum chambers built in the early 1960s to test space flight hardware in simulated space environments. The facility, built during 1961 and 1962 in the former Altitude Wind Tunnel, contained a vacuum chamber, SPC No. 1, in eastern end and a high-altitude chamber, SPC No. 2, in the larger western end.

SPC No. 1 was 100 feet long, 31 feet in diameter at one end and 27 feet in diameter at the other. An extension, removable dome, and other components were added in 1963 in order to accommodate the Centaur second-stage rocket. Centaur, acquired by NASA Lewis in October 1962, was intended carry the Surveyor spacecrafts to the moon ahead of the Apollo Program. As part of an intensive effort to improve the rocket, a full-scale Centaur was installed inside the SPC vacuum chamber for a series of qualification tests in a space environment.

The SPC No. 1 had a massive exhauster system in a pump house below the chamber that was tied into other exhauster systems at the center. After the initial air was removed from the chamber, two piston pumps simultaneously removed 12.5 cubic feet of air per second during the roughing stage. A rotary positive displacement pump pulled additional air at 500 cubic feet per second. The final vacuum is pulled down by the ten 32-inch-diameter oil diffusion pumps, which could remove 17,650 cubic feet of air per second.

In addition to the vacuum, SPC No. 1 could simulate the coldness and solar radiation of space. A large copper cold wall with its interior coated with heat-absorbing black paint was created specifically for these tests and assembled around the Centaur. The 42-foot-high wall had vertical ribs filled with liquid nitrogen which produced the low temperatures. Six panels of 500-watt tungsten-iodine lamps were arranged around the Centaur to simulate the effect of the Sun's heat on the rocket performance. Four of these arrays were on the upper end of the Centaur, and two were located near the RL–10 engines. Certain lamps could be turned on at different times to recreate the changing areas of the rocket exposed sunlight during a mission.

Centaur's autopilot, guidance, main propulsion, hydraulic, hydrogen peroxide supply, boost-pump attitude control, telemetry, tracking, range safety, and pneumatic systems were studied These studies proved that the Centaur's electrical system could perform during a two-burn flight in a space environment. The few problems that were identified were rectified before the Surveyor flights. The researches also discovered the electronics did not create or absorb heat and that the pressurization of instrument packages was not needed and actually caused performance problems.

An open area in SPC No. 1 away from the cold wall was used to conduct separation tests of the Centaur/Surveyor nose fairing in 1964. A malfunction during the separation on the previous launch almost caused the mission to fail. The SPC investigations found that internal jet expansion separation devices could successfully jettison the fairing without damaging the payload. It was also determined that all separation tests must be conducted in a vacuum environment.

The larger SPC No. 2 chamber could simulate the conditions experienced in the upper levels of the atmosphere. Some of this chamber's investigations included Atlas/Centaur separation tests, shroud jettison studies for Centaur's Orbiting Astronomical Observatory missions, and a number of liquid hydrogen propellant management studies. These included qualifying an Agena shroud converted for the Atlas/Centaur-6 mission, and redesigning the OAO shroud after a failure in 1968.

As launch vehicles and payloads became larger, the SPC became too small to continue shroud separation tests. Many of these studies were conducted in the massive Space Power Facility at Plum Brook which began operating in 1969. SPC No. 1 had been dormant since the late 1960s and SPC No. 2 since 1975. The AWT/SPC facility has played a significant role in the progression of the nation's aerospace progress--from the World War II reciprocating engine to the first turbojet models to more advanced jets of the 1950s through Project Mercury, the Apollo Program, and ensuing Centaur interplanetary flights.

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P-1047
Jan 09

Delineated by the NASA Glenn Research Center, 2009

NASA Space Power Chambers Recording Project
Historic American Engineering Record
National Park Service
United States Department of the Interior

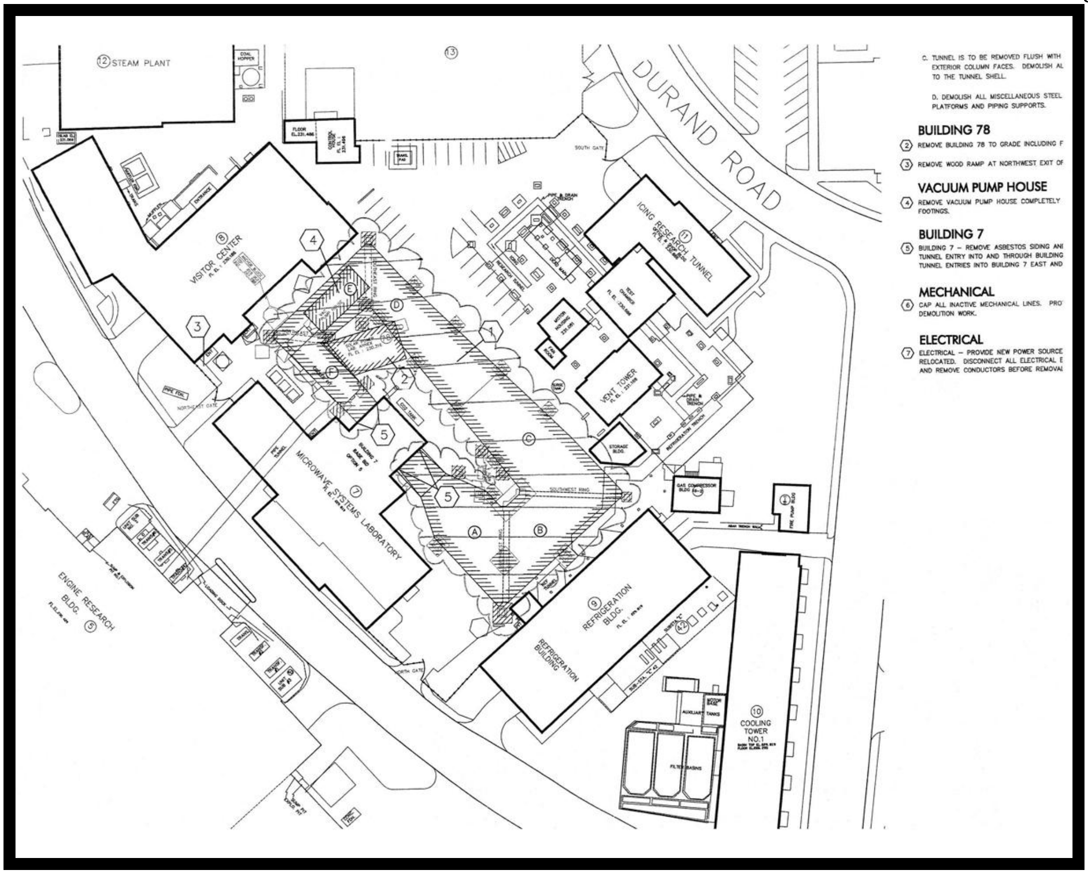
CLEVELAND

Space Power Chambers
National Aeronautics and Space Administration—Glenn Research Center
Cuyahoga County

OHIO

Historic American Engineer Record
OH-000-D

Centaur Environmental Test Setup
SPC Image No. 7: P1047/NASA Glenn Research Center



Areas of Space Power Chambers scheduled to be demolished are indicated by hash marks.
SPC Image No. 8: CF: Drawing no. A-1, Demolition of Building 7 Altitude Wind Tunnel (2005)

<u>Project Information</u>: This report was part of a wider effort to document the Altitude Wind Tunnel (AWT) and Space Power Chambers (SPC) facility prior to its demolition. This documentation was formally begun in May 2005 after Statement of Work 6.31 for the NASA Glenn History Program was finalized. The project includes the gathering of records, images, films, oral histories, and researching the facility, its tests, and significance. The resulting information is being disseminated via a book, website, multimedia cd-rom, documentary video, and this three-section construction report.

In 2005, NASA Glenn proposed to remove the entire wind tunnel circuit except for the test section within the high-bay of the Building 7. Building 7 and most of the other support buildings were not included in the demolition. Although the AWT / SPC was unique based on its sheer size alone, the maintenance costs for the facility became so high as to be justified only by the largest of research programs. Although mostly idle since the mid-1970s, this facility had a rich history and played an important role in NASA and aerospace history. For this reason NASA Glenn felt it was important to document the facility as thoroughly as possible before its destruction, and share the information with the public and within the agency.

<u>Historian</u>: Robert S. Arrighi, Wyle Information Systems, Inc.
NASA Glenn History Program Cleveland, OH

A. Physical History

Date of Construction: 1942-44, 1961-63

Excavations for the facility's foundations began in May 1942 and were completed by the end of the year. The frame of the Shop and Office Building was in place by September 1942 and completed in September 1943. Construction of the tunnel shell began in late 1942 and was completed in January 1944. The Refrigeration and Exhauster buildings were also completed in the fall of 1943.[190]

The internal components of the tunnel's western leg were removed in late 1959. The official construction of the Space Power Chambers began in July 1961 and was completed in September 1962. The addition of the dome was begun in early 1963 and completed that September.

Engineers: Original engineers included: Alfred Young, Louis Monroe, Larry Marcus, Harold Friedman, Carl Bioletti, Walter Vincenti, John Macomber, Manfred Massa of the National Advisory Committee for Aeronautics.[191] SPC engineers included: Robert Myer designed the bulkheads.

Contractors: Sam W. Emerson Company, Pittsburgh-DesMoines Steel, Carrier Refrigeration Corp, Collier, General Electric, York Refrigeration.[192]

Owner: The facility was originally constructed as a wind tunnel for the National Advisory Committee for Aeronautics' Aircraft Engine Research Laboratory. The lab's name was changed to the Flight Propulsion Laboratory in April 1947. The name was modified to be the Lewis Flight Propulsion Laboratory in 1948 in honor of the recently deceased George Lewis, the NACA's Director of Aeronautical Research. After the NACA's integration into the new NASA space agency on October 1, 1958, the name was changed once again to the Lewis Research Center. In March 1999, its name transformed again to the John H. Glenn Research Center.

Significance: The Altitude Wind Tunnel (AWT) had already served as the first wind tunnel for studying aircraft engines in the United States.[17] In the late 1950s, though, the facility shifted its focus to space and its interior was used as a large altitude chamber. The chamber was involved in several important tests for the Project Mercury Program. These included the guidance system for the Big Joe launch, posigrade and retrorockets, and the escape tower rockets. In addition, the seven Mercury astronauts and several test pilots came to the facility to train in a unique rotational test rig.

Space Power Chamber (SPC) No. 1, added to the facility between 1961 and 1963, was among the first large vacuum chambers in the country that

[17] For information on the facility's use as a wind tunnel see the Altitude Wind Tunnel portion of this report.

could simulate the environment of outer space. The SPC No. 1 vacuum tank was rivaled in size only by the smaller Mark I tank at Arnold Engineering Development Center.[193]

The SPC's significance is directly linked to the success of the Centaur second-stage rocket. The Centaur's original mission was to carry the Surveyor spacecraft to soft-land on the moon and photograph the lunar surface in preparation for the Apollo Program. The SPC was directly involved with approximately twelve Centaur missions, but its testing influenced just about every subsequent mission. SPC No.1 was used to conduct a series of long-term systems tests on a full-scale Centaur and nose cone separation tests for multiple Surveyor missions. The other chamber could simulate the conditions experienced in the upper levels of the atmosphere. Some of this chamber's investigations included Atlas/Centaur separation tests, shroud jettison studies for the Orbiting Astronomical Observatory missions, and a number of liquid hydrogen propellant management studies. Centaur has remained a successful workhorse, though, carrying Pioneer, Viking, Voyager, the Orbiting Astronomical Observatories, Cassini, and many other spacecraft.

A NASA Lewis researcher is interviewed in the SPC shop area in front of Centaur rocket
SPC Image No. 9: 1963-67458/NASA Glenn Research Center (1963)

Topography:

The property on which the Space Power Chambers Group is located was part of the original two hundred acre area acquired from the Cleveland Municipal Airport by NASA's predecessor the National Advisory Committee for Aeronautics (NACA) for an engine research laboratory. The site, acquired in late 1940, had previously been used by the airport for parking and grandstand area for the National Air Races.[194] The airport borders the center on the east. The rest of the border loosely follows the Rocky River which bows to the northwest around the main campus. The river valley is densely forested, but the main portion of the NASA land is flat and featureless.

View of NASA Lewis from the northeast with Cleveland Municipal Airport to left, the Rocky River valley to the right, and the city of North Olmsted behind
SPC Image No.10: 1963-66568/NASA Glenn Research Center *(1963)*

The Space Power Chamber facility is on a flat, featureless area at an elevation ranging from 751 to 759 feet above sea level. The nearby area contains several other laboratory buildings, including the Engine Research Building, the Icing Research Tunnel, and several small Icing Research Tunnel support buildings. These original buildings are of similar design and appearance, which gives the area a unified appearance.

Original Construction:

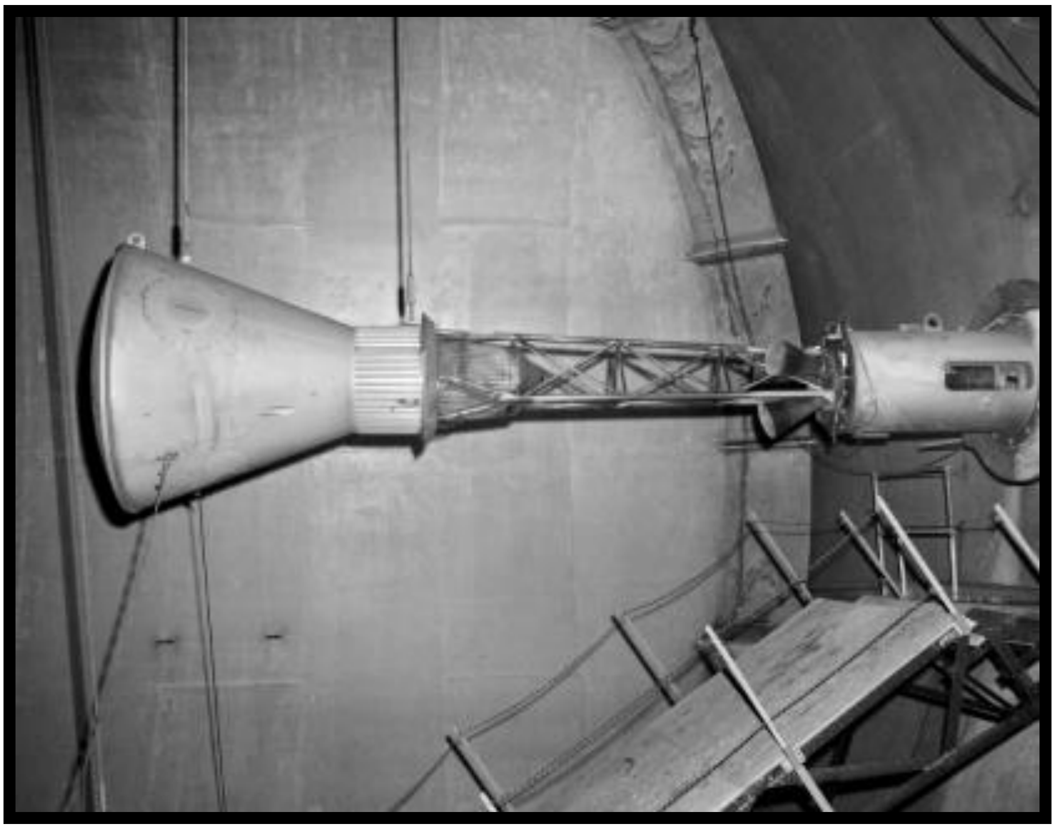
The original design for the tunnel began in 1940 at the National Advisory Committee for Aeronautics (NACA)'s Langley Memorial Laboratory and Ames Aeronautical Laboratory. The tunnel's distinctive shell, test section, and electrical drive system were designed at Ames by Carl Bioletti, Walter Vincenti, John Macomber and Manfred Massa. Most of the other components were engineered at Langley by Al Young, Larry Marcus, Harold Friedman, and others.[195]

The Sam W. Emerson Company was the prime contractor for the general construction work. They commenced the excavations for the facility in the spring of 1942 and completed the task by late December.[196] The construction of the Office and Shop Building was completed in September 1943. This was followed closely by the completion of Refrigeration and Exhauster buildings.[197] The Pittsburgh-Des Moines Steel Company fabricated and constructed the shell.[198]

Planning for the refrigeration system started at Langley in April 1942, but was soon taken over by the Carrier Corporation. Carrier's cooling system for the AWT was the largest refrigeration system in the world. Carrier provided all the system's equipment, and was then contracted to install the system.[199] The original control room, test section, and tunnel were completed in January 1944 and the facility ran its first test on February 4, 1944.[200]

Original construction of east leg of AWT and future Space Power Chamber No. 1
SPC Image No. 11: 2007-02297/NASA Glenn Research Center *(1943)*

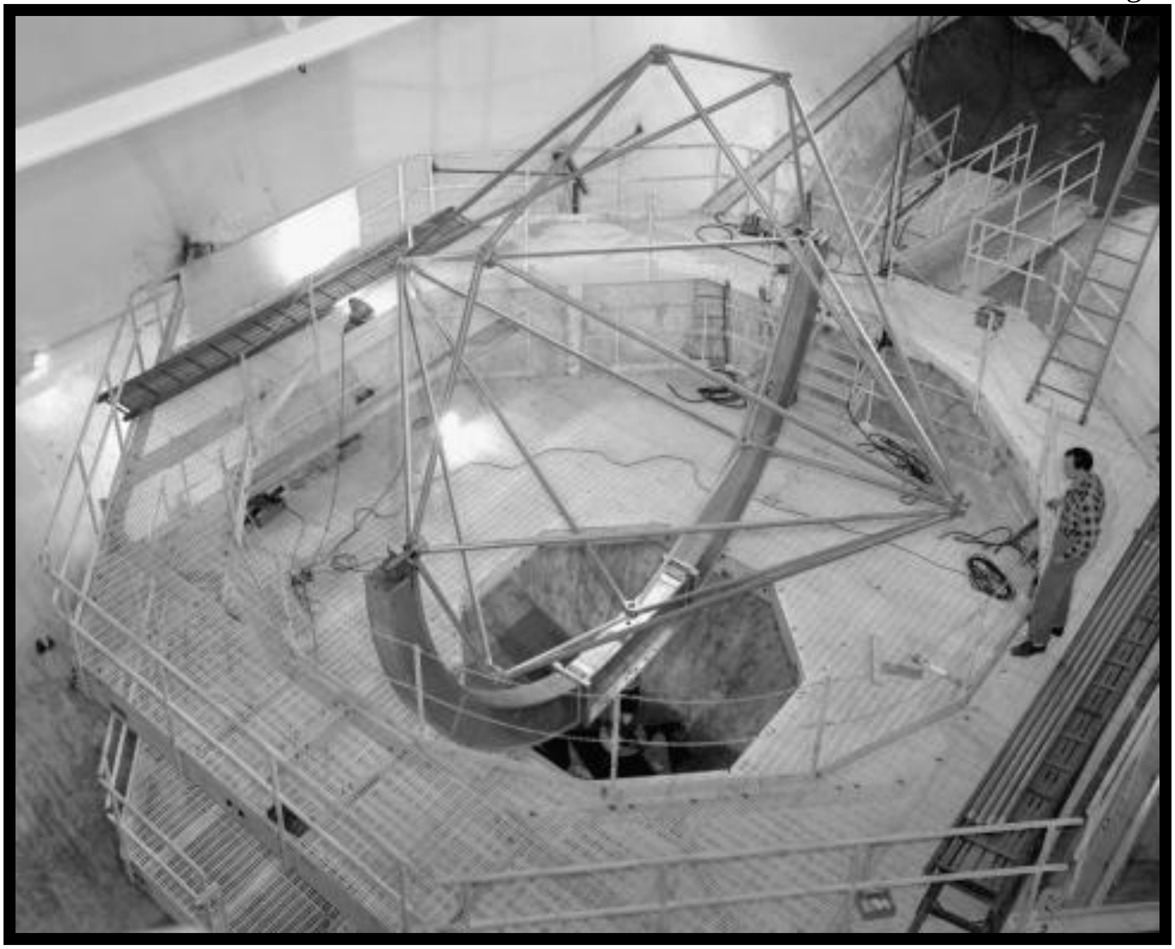
After fifteen years of wind tunnel, it was decided that the facility would not be used for its airflow generation, but rather for its large internal space and altitude simulating capabilities. Although the decision to create the Space Power Chambers (SPC) would not be made for another two years, the first unofficial steps began between September 1959 and April 1960. The cooling coils, make-up air pipe, and turning vanes had been removed from the west end of the tunnel. An elevated walkway and banks of lights were erected along the western wall. A catwalk was erected along the ceiling of the western leg. The tunnel's interior was also cleaned and repainted. Various fittings were installed on the floor and walls as part as several temporary test stands or setups.



Project Mercury escape tower rocket test in AWT after vanes and cooling coils were removed
SPC Image No.12: 1960-53520/NASA Glenn Research Center (1960)

For approximately one year beginning in April 1959, a gimballing system was installed at the base of the tunnel's throat section. This was a three-axis rig with a pilot's chair mounted in the center surrounding by three 21-foot diameter cages. A two-level steel platform used to enter and view the rig was constructed around it. The top level of the platform was even in height with the test section and the lower level was approximately 3 feet above the tunnel floor.[18]

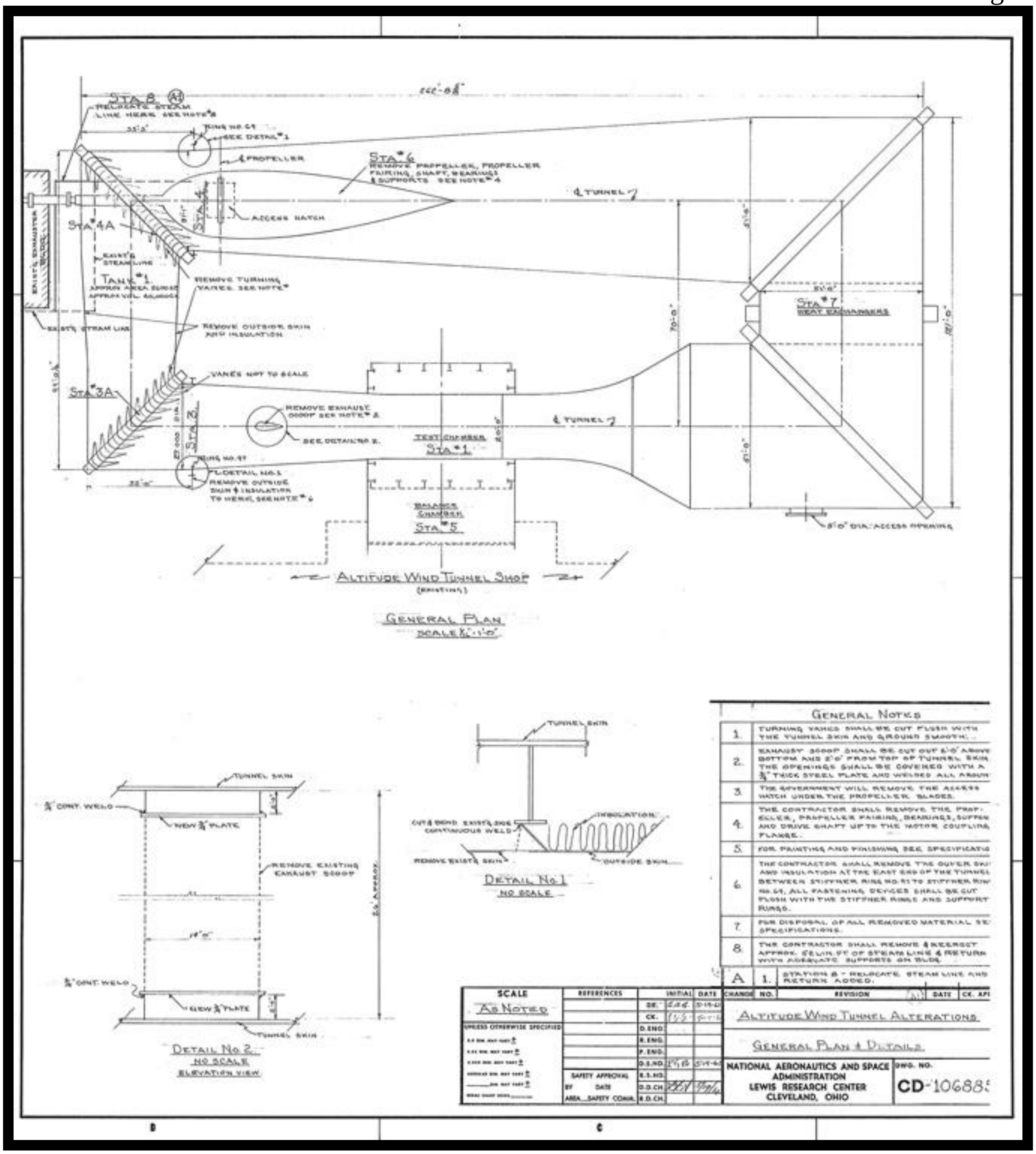
[18] For additional description of the Multi Axis Space Training Inertial Facility, see the Space Power Chamber Architectural Information section of this paper.



Installation of gimbal rig near the AWT throat section with vanes and make-up air nozzle removed
SPC Image No. 13: 1959-50329/NASA Glenn Research Center (1959)

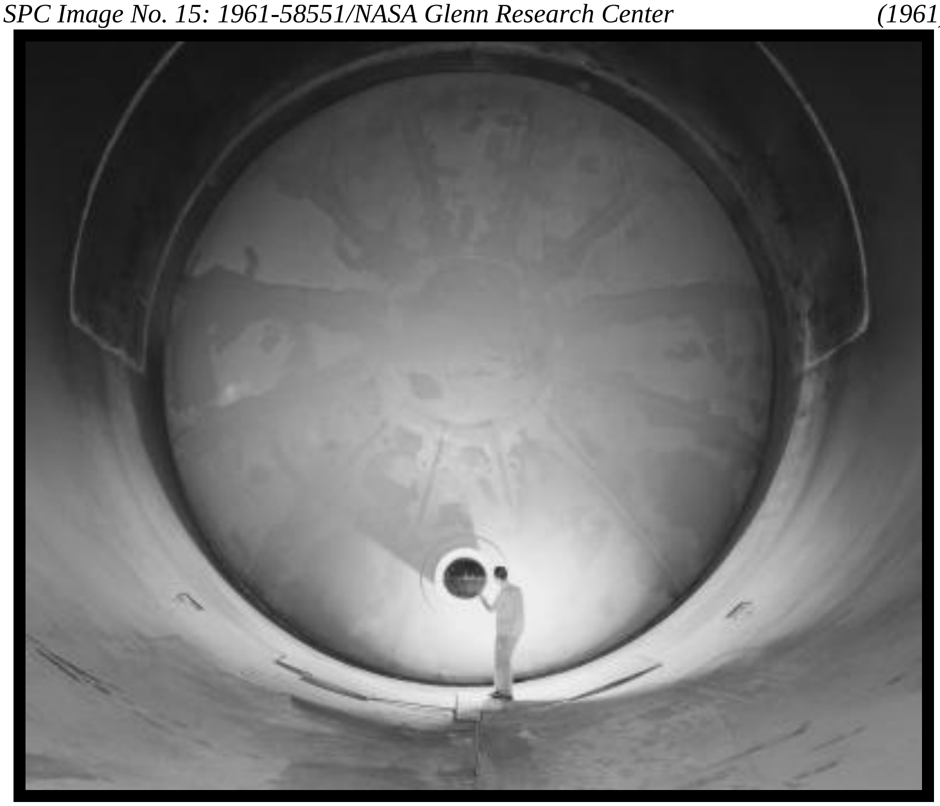
Starting in 1961 a number of steps were taken to convert the wind tunnel into two large test chambers. This included separating the chambers from each other, resealing the outer shell, adding a removable dome, and upgrading the exhaust system for space simulation. In addition, the existing drive shaft, fan, turning vanes, and exhaust scoop were removed from the east end of the tunnel.

Three bulkheads were installed inside the tunnel to create the two chambers. The largest was the 31-foot diameter seal between structural ribs No.70 and 69 near the southeast corner of the southern leg where the wind tunnel fan was located.[201] A section of the upper half of the tunnel near was cut out and removed using a crane. The crane was then used to install the large red bulkhead, one half at a time, in the opening. Another seal was created east end of the former test section which completed the sealing off the entire eastern leg of the tunnel for SPC No. 1.



Drawing showing plans for removal of AWT fan, air scoop, and turning vanes for SPC.
SPC Image No.14: NASA CD-106885 01 A

Bulkhead section being lifting into opening cut into southeast corner of tunnel
SPC Image No. 15: 1961-58551/NASA Glenn Research Center (1961)

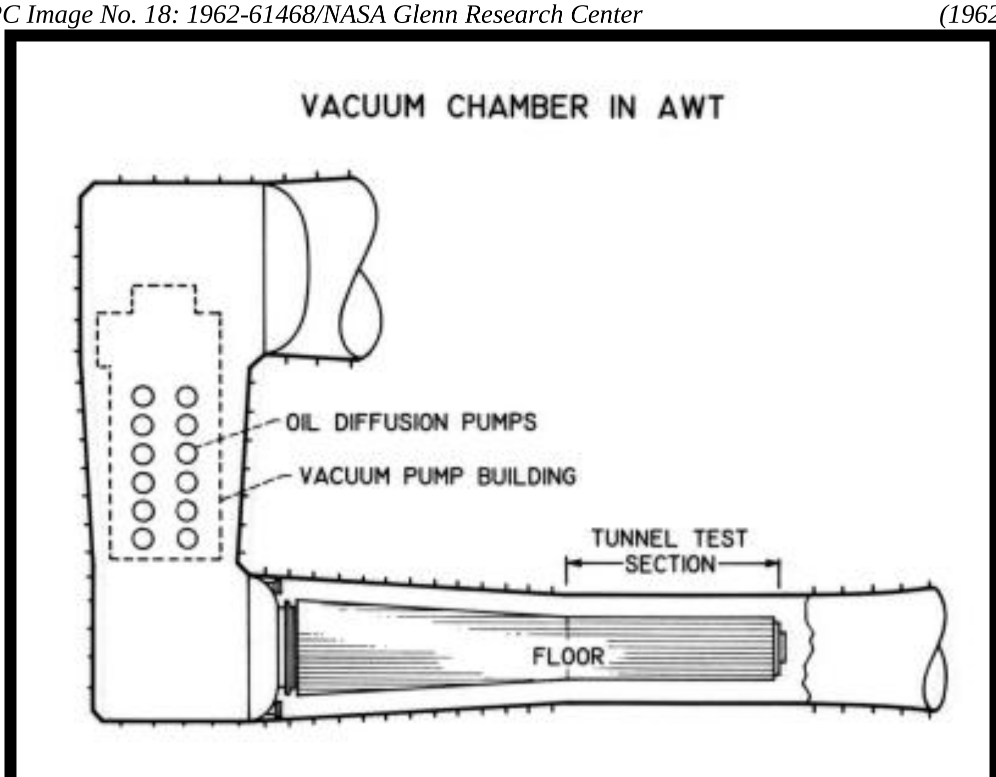


View facing east of bulkhead installed in southeast corner of tunnel
SPC Image No. 16: 1962-60343/NASA Glenn Research Center (1962)

Outer steel layer of wind tunnel is removed so inner layer can be rewelded to create higher vacuum seal
SPC Image No. 17: 1961-57388/NASA Glenn Research Center (1961)

During the conversion process, the outer skin of the tunnel was removed to check the inner shell for leaks. It was found that the entire SPC No. 1 chamber area had to be rewelded. It was suspected that this was due to the original hurried war-time construction. The rewelding slow the conversion progress down and drove up costs. [202] The insulation and outer shell were not reinstalled. Since the larger SPC No. 2 chamber would be used for upper atmospheric tests, it did not have to rewelded, and the insulation and outer shell remained in place.

Interior of SPC No. 1 with diffusion pump portals in the floor and prior to the addition of the dome
SPC Image No. 18: 1962-61468/NASA Glenn Research Center (1962)



SPC No. 1 diagram showing Vacuum Pump House, bulkheads, and flooring in former tunnel test section
SPC Image No. 19: CS-1961-22859/NASA Glenn Research Center (1961)

The interior of the 30-foot diameter 100-foot long SPC No. 1 was sandblasted and repainted with a double-coat of aluminum paint that would not outgas in a high vacuum.[203] The AWT's exhaust system was replaced by a new oil diffusion-based system which could create a 10 to the -6 mm of mercury pressure level.[204] A new Vacuum Pump House was constructed underneath SPC No. 1 to house this new vacuum system. The ten diffusion pumps were connected from below to the chamber floor.

View from west of extension and dome created near the southeast corner of SPC No. 1
SPC Image No. 20: 1963-65692/NASA Glenn Research Center (1963)

The Centaur rocket program was transferred to NASA Lewis in October 1962 just as the SPC was nearing completion. It was decided that the new vacuum chamber would be an ideal place to study the behavior of the rocket's systems in a space environment. It was at this time that the SPC's most distinguishing trait, a 22.5 foot diameter cylindrical extension with a detachable dome, was created near the southeast corner. The extension was created in the ceiling of the chamber so that the full-size Centaur could be vertically positioned inside the chamber. The extension was capped with a removable dome so that the Centaur could be lowered inside by a crane.[205]

Another 20-foot diameter bulkhead was inserted on the western end of the test section before the throat section. This along with the 32-foot seal in the southeast corner created another test chamber, SPC No. 2 in the remainder of the tunnel.[206] This large J-shaped chamber was used for a number of Centaur shroud separation and propellant behavior tests. Previous test equipment, including the gimbal spin rig, was removed from the tunnel. Although the wind tunnel internals were removed and the walls painted for the Project Mercury tests, the area was cleaned up and repainted for the new SPC chamber. The existing tunnel exhausters were sufficient for simulating the altitudes of the upper atmosphere at which shrouds would be jettisoned.[207]

View of the southwest corner of SPC No. 2 as it undergoes renovation after the Project Mercury tests
SPC Image No. 21: 1961-57714/NASA Glenn Research Center (1961)

The clamshell lid for the former tunnel test section was removed and a metal bridge and stairway into the tunnel were built at the east end of the test section. Steel grated flooring was installed in the bottom of the test section. An overhead rail crane was mounted in the northeast leg to allow transfer of articles from the test section in the high bay into SPC No. 1.

A new control room for SPC No. 1 which sought to replicate the launch control room at Cape Canaveral was created underneath the former tunnel test section. Instrumentation cables traveled from the east wall directly up to the dome. The existing wind tunnel control room was modified to run the tests in SPC No. 2. This primarily involved rewiring and altering the control panels.

Construction of control room for SPC underneath former wind tunnel test section
SPC Image No. 22: 1961-58575/NASA Glenn Research Center (1961)

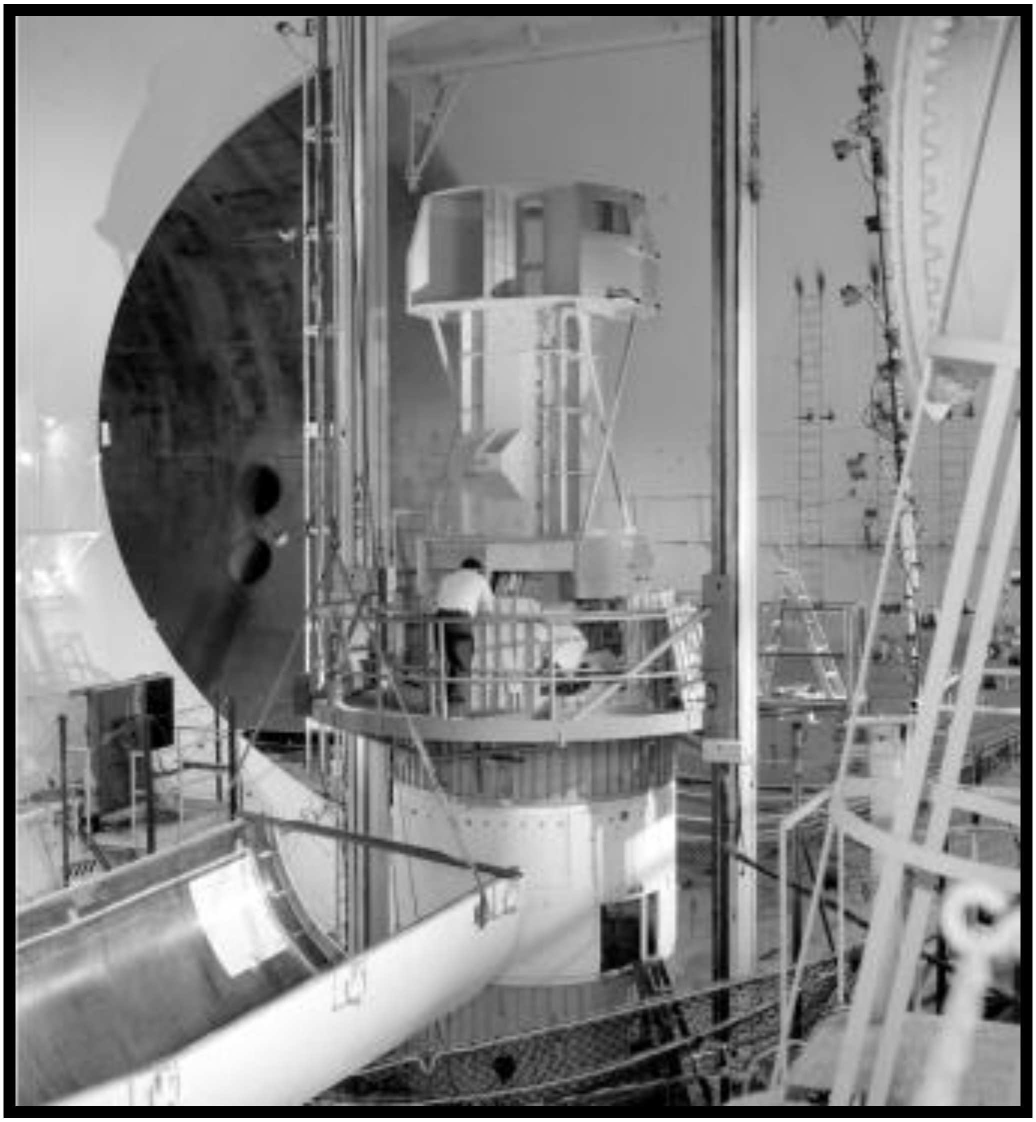
Although the SPC was completed in September 1962, the modifications and setup for the Centaur Program pushed back the first tests for over a year. The first separation tests in SPC No. 2 began in October 10, 1963. The Centaur rocket was placed in SPC No. 1 on March 19, 1964 and the environmental testing began that December. Surveyor separation tests began in SPC No. 1 during the interim in July 1964.

Alterations:

The SPC facility did not undergo any major alterations during its operational period from 1963 to 1975. Various platforms, hooks, braces, and other temporary items were added to the interior for test setups.[19] Some of these additions were left in place afterwards, while most others were cut off near their bases.

SPC No. 2 included an oval platform elevator could be raised the entire height of the chamber on two vertical steel girders. The elevator's 11-foot diameter interior opening allowed it to be placed around the payload shrouds to assist in separation test preparations. [208]

[19] For additional information on Centaur setup in SPC No. 1 see the Architectural Information: Space Power Chamber section of this report.



Platform elevator around Centaur payload inside SPC No. 2
SPC Image No. 23: 1972-03933/NASA Glenn Research Center (1972)

In an effort to test deceleration pellets for the new Zero Gravity Facility, a penetration was installed in the top of SPC No. 2 in late 1965. A 5-foot diameter and over 20-foot tall deceleration stand was mounted to the chamber floor. A temporary shack-like enclosure was built on the tunnel roof to protect the accelerator apparatus. A tubular device extended to deceleration bucket on the chamber floor.[209]

The SPC control room and its Shop and Office Building were transformed into the Microwave Systems Laboratory in the early 1980s.[20] This included the repurposing of the SPC No. 1 control room and sealing of the high-bay area.

[20] For addition information on Microwave Systems Lab see the Support Buildings section of this report.

B. Events History

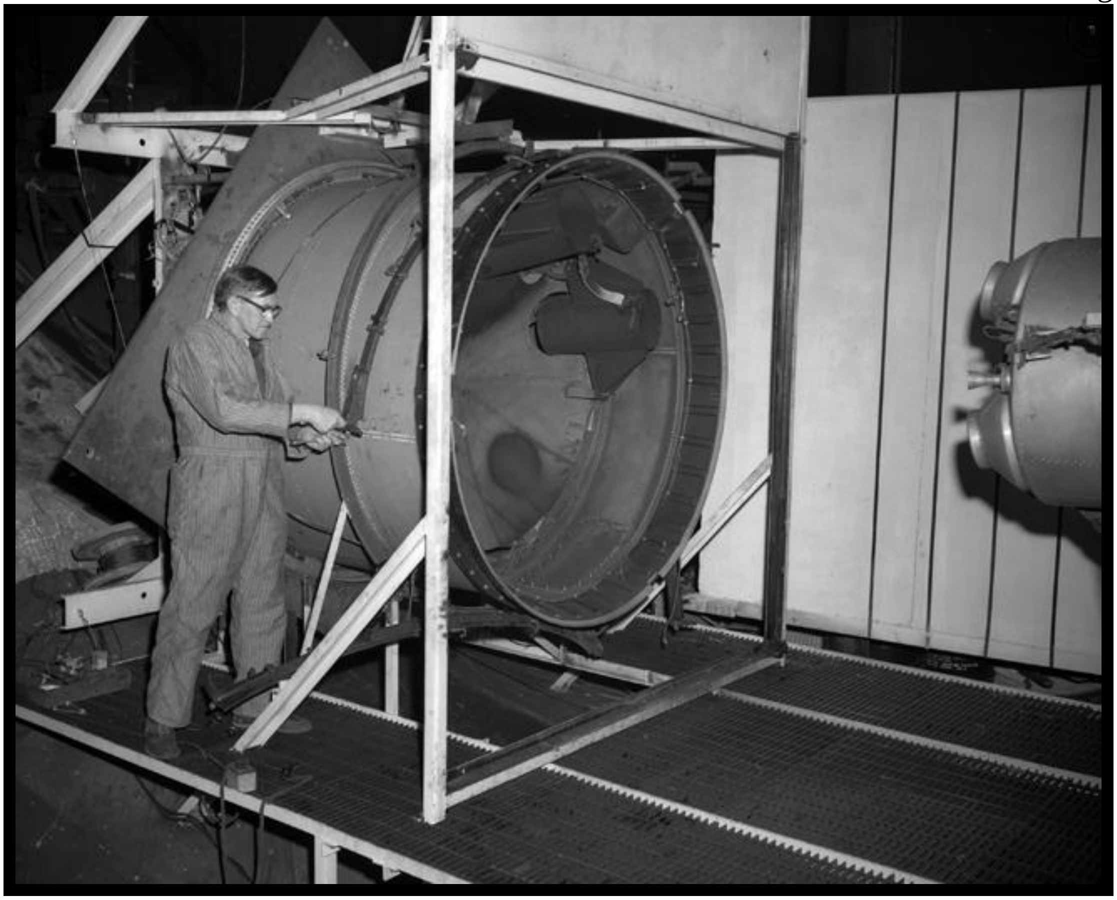
Project Mercury: In response to the Soviet Union's launch of the Sputnik I and II satellites in 1957, President Eisenhower pushed for the creation of a civilian space agency. NACA Lewis, which had been working on rocket propulsion and high-energy fuels for years, was influential in the decision to base the new agency on the existing NACA laboratories. The National Air and Space Administration (NASA) officially came into being on October 1, 1958, and the NACA Lewis Flight Propulsion Laboratory became the NASA Lewis Research Center. The center underwent a major reorganization and for the next ten years concentrated its efforts almost exclusively on the space program.

NASA's first step would Project Mercury—a series 21 unmanned and 7 single-person orbital flights. On October 15, 1959 the team coordinating Project Mercury, Space Task Group (STG), met to allocate the testing assignments among the NASA centers. The Altitude Wind Tunnel (AWT) facility at Lewis would be used extensively, but not as a wind tunnel. The tunnel's interior and altitude simulation would be utilized to test the Mercury/Atlas separation system, calibrate retrorockets, and test the attitude control system. The facility was also selected to study the escape tower rocket plume and train astronauts how to bring a spinning capsule under control.[210]

The first attempt to launch a capsule on a full-size Atlas booster was dubbed Big Joe. Big Joe was a single mockup Mercury capsule without an escape tower, life support, or other systems. The flight was designed to simulate the reentry of the capsule without actually placing it in orbit and test the launch and recovery processes.[211] NASA Lewis asked to assemble the capsule and design the electronic instrumentation and automatic stabilization system.[212]

The STG decided to forgo their original plans to use balloons and instead employ the AWT to qualify the capsule and all its systems at high altitudes before its launch.[213] A Multiple Axis Space Test Inertial Facility (MASTIF) was created inside the AWT to simulate the various motions the capsule would be subjected to. During the early summer of 1959 qualifications, the attitude control and retrorockets were fired and the capsule exposed to simulated altitudes up to 80,000 for long periods of time.[214] On September 9, 1959, Big Joe MA-1 was successfully launched on an Atlas D missile, and the mission objectives achieved. [215]

The Mercury capsule had six rockets on a "retro-package" affixed to the bottom of the capsule. Three of these were posigrade rockets used to separate the capsule from the booster and three retrograde rockets used to slow the capsule for reentry into the earth's atmosphere. There were several problems while qualifying the posigrade and retrograde rockets, and there was no backup system if the retrograde braking system failed. The STG assigned NASA Lewis and Ames the task of resolving the issue.[216]



Mercury capsule/Redstone booster separation test inside of the AWT
SPC Image No. 24: 1960-52795/NASA Glenn Research Center (1960)

Full-scale separation tests using mockups of both Redstone and Atlas boosters were conducted in the AWT at altitudes comparable to the upper atmosphere. As the capsule's posigrade rockets were fired and the capsule jettisoned forward on a tether. The AWT tests in January and February 1960 determined that a gas build-up in the Redstone ballast section actually accelerated the separation process.[217] Mercury Atlas separation tests in mid-April ensured that the firing of the posigrade rockets did not injure any other components and determined the actual boost level of the posigrades.[218]

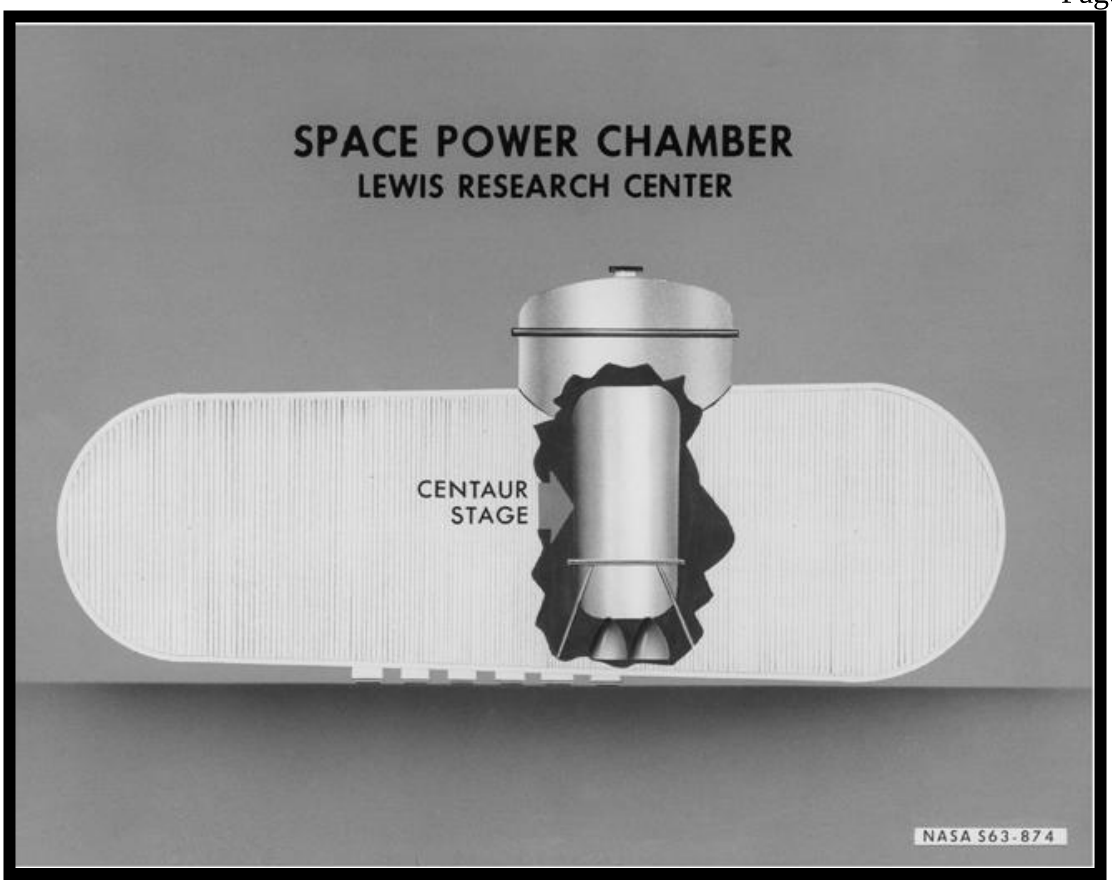
Three Mercury retrorocket qualifications tests were also begun in April 1960 in the AWT. A retrograde thrust stand was erected in the southwest corner of the tunnel. The studies showed that a previous issue concerning delays igniting the propellant had been resolved. Follow-up test runs verified reliability of the coated igniter's attachment to the propellant grain.[219] In addition, they calibrated the capsule's retrorockets so they would not alter the capsule's position when fired.[220]

Mercury capsule retrorocket test setup inside the AWT
SPC Image No. 25: 1960-53149 /NASA Glenn Research Center (1960)

During late spring 1960 the AWT was also used to determine whether the plume from the Mercury capsule escape tower rocket would engulf the capsule during an emergency separation from the booster. The escape tower was a 10-foot steel rig and rocket attached to the nose of the Mercury capsule. The tower had its own propulsion system which could be used to jettison the capsule to safety in the event of launch vehicle malfunction on the launch pad or any point prior to separation from the booster.[221] The tunnel was evacuated to approximately 100,000 feet altitude and the escape tower was mounted to the tunnel wall with a mock-up Mercury capsule at the end. Three different escape tower motors were successfully fired.[222]

One of the highest profile tests ever conducted in the AWT was the Multi Axis Space Test Inertia Facility (MASTIF), informally referred to as the "Gimbal Rig." The MASTIF was a three-axis rig designed the previous year to test the Big Joe guidance system. It was modified with a pilot's chair mounted in the center, control stick, and mock control panel. The MASTIF used during February and March 1960 to train the Mercury 7 astronauts how to reign in a tumbling spacecraft. It was also used to study the effects of rapid rotation on the pilots' eyesight. The rig was set up in the northwest corner of the tunnel. The pilot was strapped in on a foam couch in the center of the rig with only the arms free to operate communications and panic buttons and a stick that controlled the small nitrogen jets that ran the movement of the MASTIF.[223]

John Glenn prepares for a test in the Multi-Axis Space Inertial Facility inside of the AWT
SPC Image No. 26: 1960-52745/NASA Glenn Research Center *(1960)*



Drawing of SPC No. 1 with extension and dome for Centaur rocket
SPC Image No. 27: 1964-69473/NASA Glenn Research Center (1964)

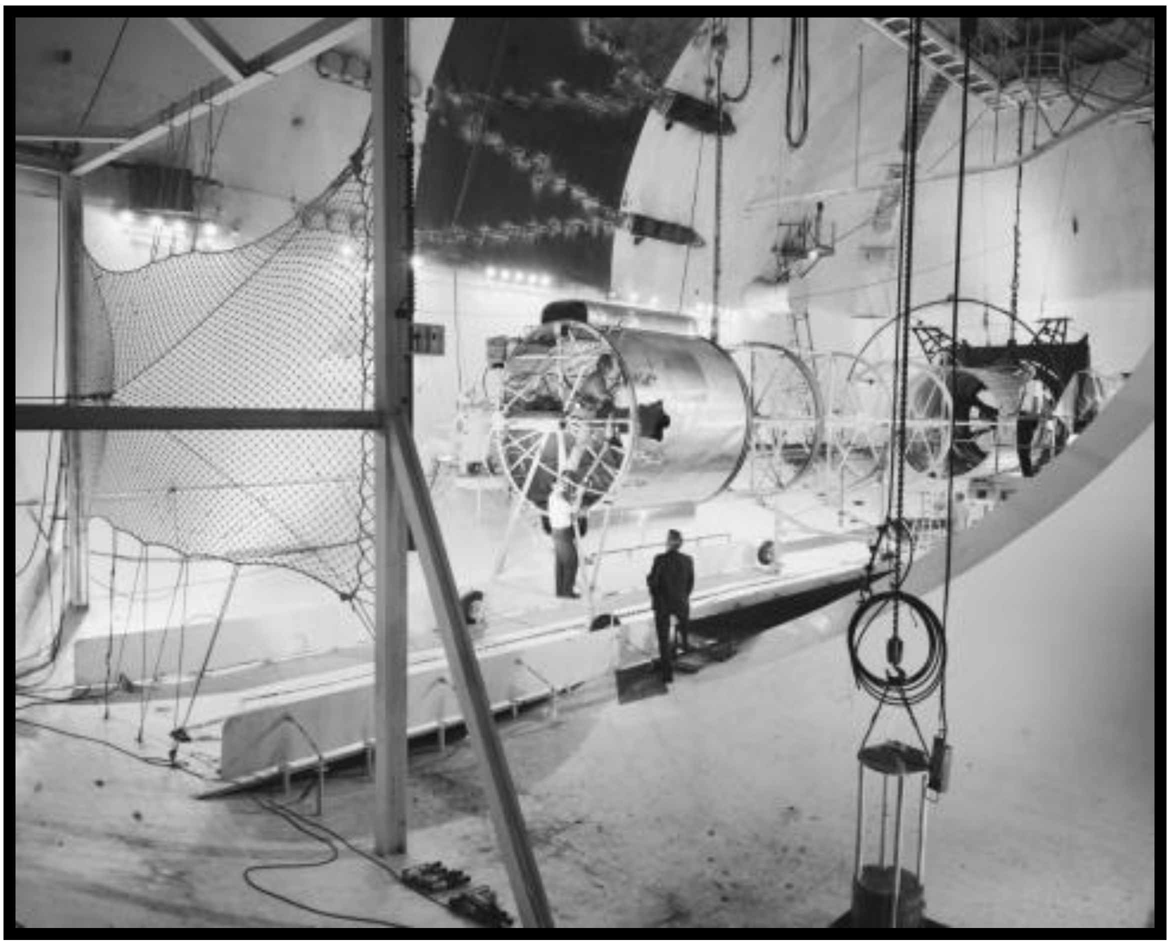
Centaur Program: Between 1958 and 1960, the lab had refocused its efforts almost completely towards the space program. NASA Lewis built or reassigned 19 space-related facilities during the Apollo Program and mothballed numerous aeronautics facilities.[224] With 4700 employees, Lewis had become the second largest NASA center by 1964.[225]

It was during this rich period of growth that the Centaur second-stage rocket program, Lewis' most important contribution to the space program, was transferred to Cleveland. While it was designed solely for the Surveyor missions to explore the moon's surface, Centaur went on to perform scores of missions. These included Pioneer, Viking, the Lunar Orbiter, Orbiting Astronomical Observatories, Cassini, and others. The AWT would play a key role resolving early problems with the Centaur.

The Centaur Program was created by the Department of Defense in 1958, but shifted to the NASA's Marshall Space Flight Center on November 8, 1959.[226] The first launch on May 8, 1962 failed shortly after lift-off due to a Centaur malfunction, and the program was on the verge of cancellation. Marshall engineers had never felt comfortable with Centaur's non-traditional design or liquid-hydrogen propellant. NASA Lewis had been performing work with hydrogen and other non-traditional fuels for years and was confident in its safety and the advantages. In October 1962 the program was transferred to Lewis.

Lewis was steadily building up space-related test facilities in Cleveland and at its satellite Plum Brook Station. Among these were the two new large test chambers recently created inside the former AWT. One chamber could replicate an outer space environment and the other that of earth's upper atmosphere. The new facility was officially renamed the Space Power Chamber (SPC) on September 12, 1962.[227]

NASA Lewis' nuclear propulsion and power programs were also gearing up at this time, and the SPC No. 1, the space tank, had actually been built to study the SNAP-8 nuclear power generator.[228] Plans for the chamber were changed with the transfer of the Centaur Program. Another year of construction was needed to add an extension and domed lid to SPC No. 1 to accommodate an upright Centaur.

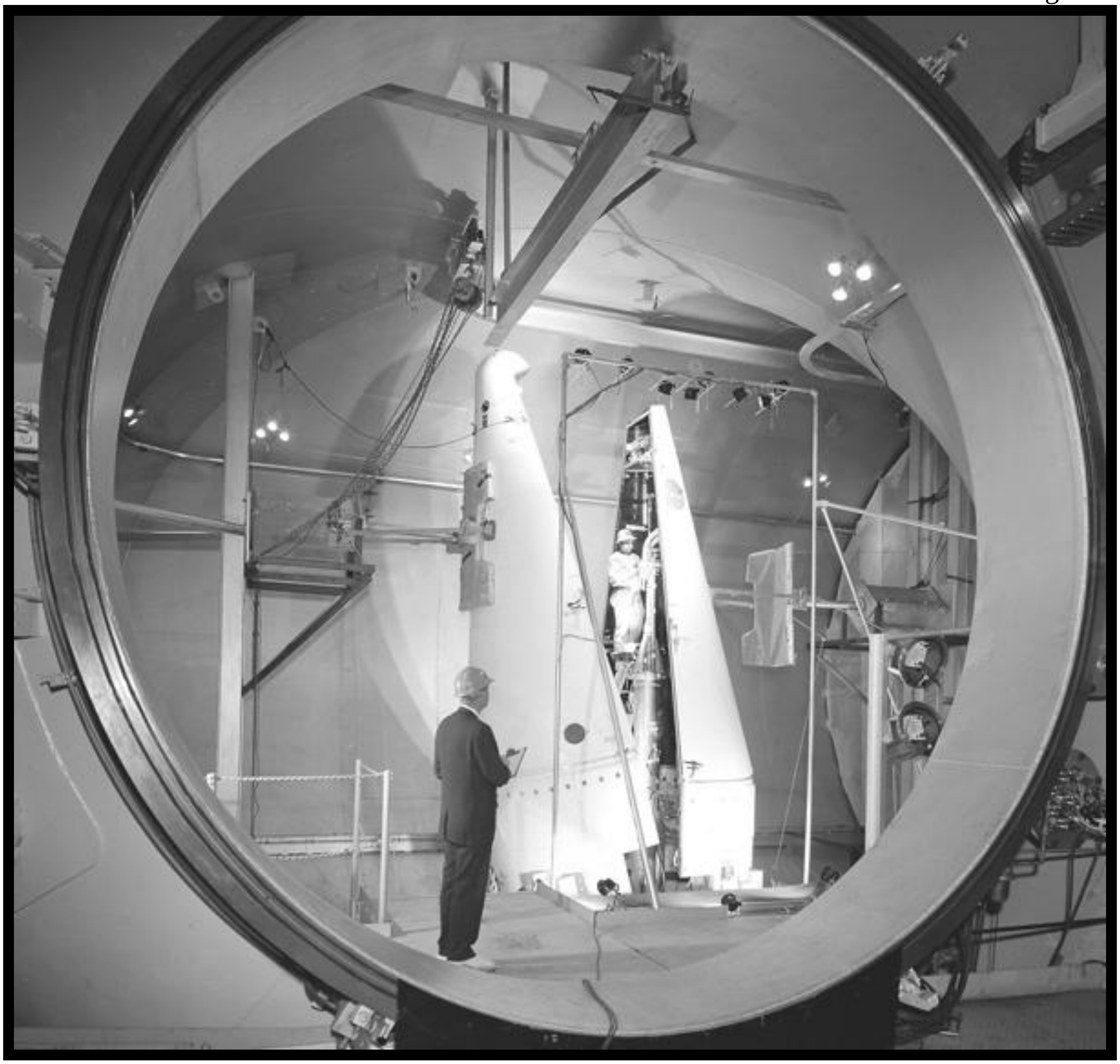


First tests in the Space Power Chambers were a series of Atlas/Centaur separation studies in SPC No. 2
SPC Image No. 28: 1963-66039/NASA Glenn Research Center (1964)

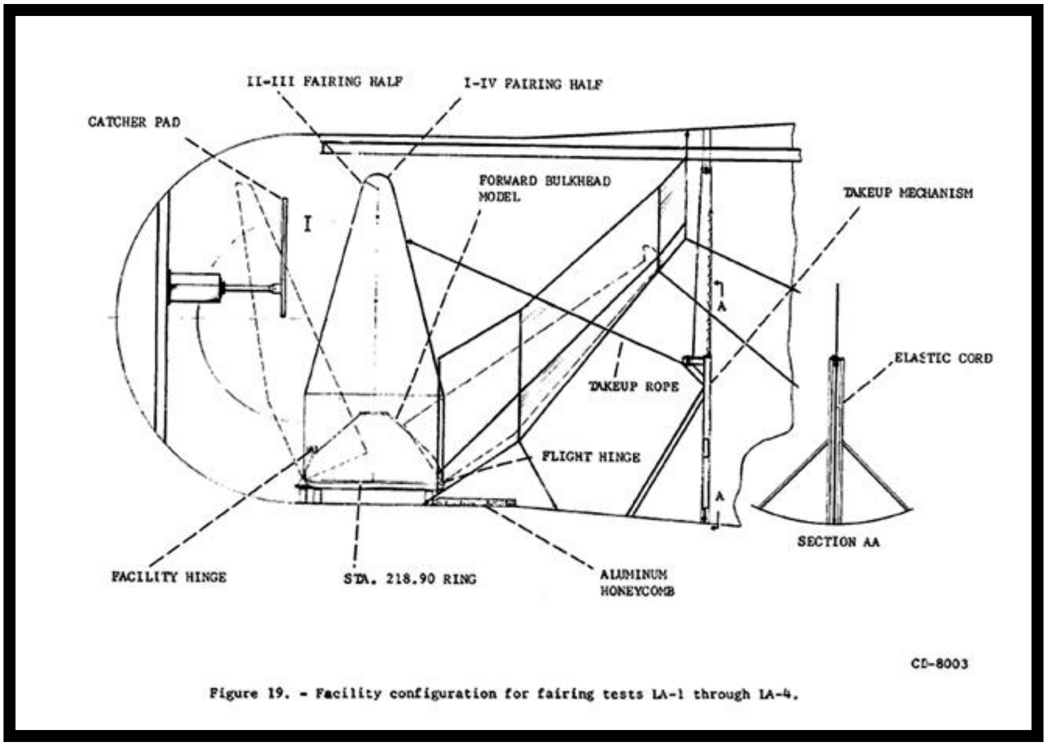
Surveyor Nose Cone Tests: The first studies in the new facility, however, were a series of Atlas/Centaur separations conducted in SPC No. 2 during the fall of 1963. The simulated Atlas/Centaur vehicle was hung horizontally in the large chamber. When the retrorockets fired, the Atlas model on wheels was jettisoned into a net. It was found that the firing of the eight retrorockets was inconsistent. Follow-up studies with standard and alternate versions of the rocket igniters firing at pressure altitudes up to 98,000 feet revealed the causes of the unpredictability. The lighters were redesigned by the manufacturer and requalified in the SPC.[229] In addition the rockets were configured in such a way that one rocket misfiring would not mar the separation.[230] A new method of loading the propellant was also derived from these studies. The increased impulse significantly reduced the separation time, which reduced the danger of collision between the two stages during separation.[231]

After successful launches of Lewis-led Atlas/Centaur-2 and 3, NASA Lewis researchers conducted a series of nose fairing tests in anticipation of the next Centaur launch scheduled for late 1964 which would attempt to place a mock-up Surveyor spacecraft into orbit. Although ambient atmosphere separation tests prior to Atlas/Centaur-3 were successful, the separation during the AC-3 launch had difficulties that nearly caused a mission failure. It was felt that the low pressure of space affected the bottle used to activate the explosive bolts. The SPC No. 1's space simulation could determine any design faults in the AC-3 fairing and flight-qualify the AC-4 shroud components.[232]

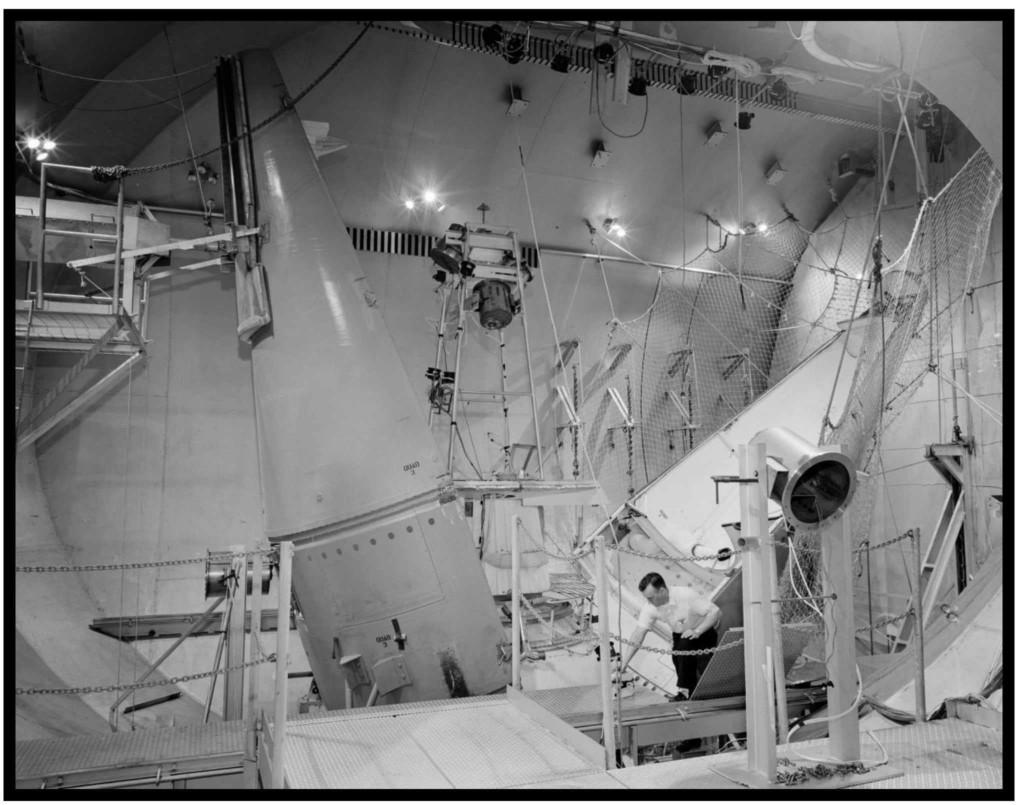
The tests of the fairing were conducted in the northeast corner of SPC No. 1 from July 31 to November 24, 1964 with a bevy of high-speed cameras were installed. After numerous modifications and adjustments Lewis researchers determined that internal jet expansion separation devices could successfully jettison the fairing without damaging the payload. It was also determined that these separation tests must be conducted in a vacuum environment.[233] All modifications implemented between the AC-3 and AC-4 missions were verified in the SPC. As a result AC-4 was the first Centaur mission to have an error-free shroud jettison.[234]



Surveyor nose cone during tests in the northeast corner of SPC No. 1 for the AC-4 mission
SPC Image No. 29: 1964-71092 /NASA Glenn Research Center *(1964)*



SPC No. 1 setup for Surveyor nose cone separation tests
SPC Image No.30: NASA TM X-52290, Figure 19



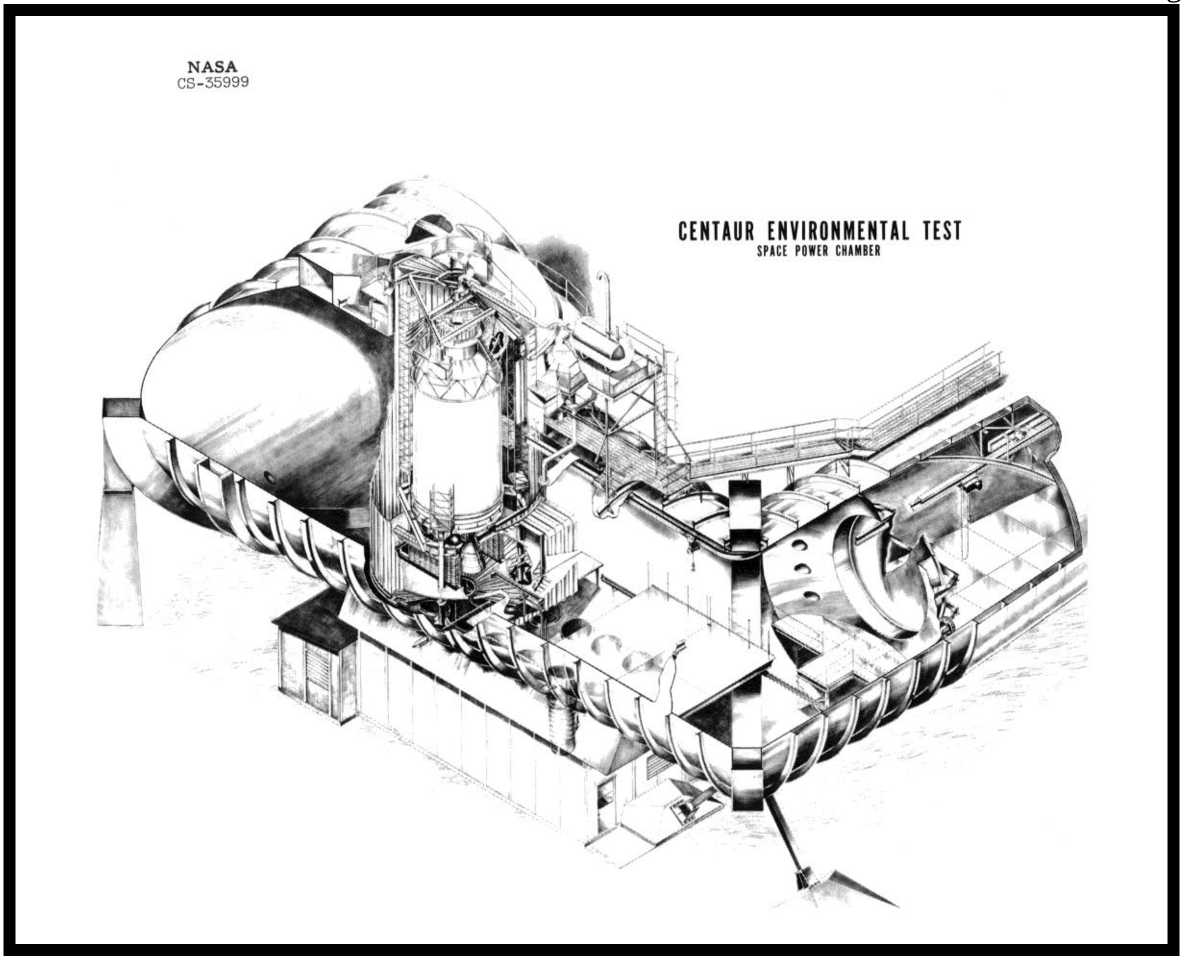
Surveyor shroud qualification for the Atlas/Centaur-6 mission in the northeast corner of SPC No. 1
SPC Image No. 31: 1965-01022/NASA Glenn Research Center (1965)

Despite the fact that the fiery failure of AC-5 was caused by the booster engines, there were modifications made to Centaur and the nose cone that required requalification of the shroud. This flight qualification of the new shroud was conducted from May to July 1965 in the SPC No. 1. These studies tested the nose cone design, determined the impact on the payload envelope, and studied the shroud's effect on the new, thinner Centaur fuel tanks.[235] Although the payload envelope had to be altered, NASA Lewis researchers approved the entire nose fairing design and load limits for flight.[236] The successful August 11, 1965 of AC-6 restored NASA's confidence in the Centaur's capabilities.

<u>Centaur Environmental Testing</u>: During the buildup to the Surveyor flights, Lewis researchers wanted to determine how the Centaur's auxiliary propulsion, hydraulic, pneumatic, and electrical systems behaved in a space environment.[21] Of particular concern was the effect of the heat from the electronics on the cryogenic liquid-hydrogen propellant. A Centaur 6A rocket was flown to Cleveland on a C-130 aircraft and transported via flatbed truck to the SPC shop area in October 1963. For several months General Dynamics personnel worked with NASA Lewis researchers as they studied and began reassembling the rocket in shop area. The 6A model had to be reharnessed electronically and updated to properly replicate the Centaur that would be performing the AC-4 mission.[237] On March 19, 1964 the Centaur was rolled out of the shop. A 100-foot crane lifted the lid off the dome, then lifted the rocket into the air, and lowered into a test stand inside the chamber.

The Centaur 6A is inspected in the SPC shop area prior to insertion into the chamber
SPC Image No. 32: 1963-66502/NASA Glenn Research Center (1963)

[21] For details on the test set-up and space simulation devices see the Architectural Information: Space Power Chamber section of this report.



Cutaway drawing of SPC No. 1 showing the installation of the Centaur rocket
SPC Image No. 33: CS-35999/NASA Glenn Research Center

SPC No. 1 sought to replicate all aspects of outer space except microgravity and meteor impingements. The vacuum was pulled down to 10 to the -5 mm of mercury pressure level by the new oil diffusion pumps.[238] The coldness was supplied by a nitrogen-filled cold wall erected around the Centaur. The radiation of space was created using banks of quartz lamps. In addition a pneumatic system rotated the rocket's RL-10 engines as they would be during flight.[239]

After the proper vacuum was achieved in the tank, the rocket was brought to launch temperature, the electrical system was turned on, and the test commenced. The first three minutes of the test were the Atlas booster phase. The Centaur systems were activated immediately afterward the simulated separation. This involved prestarting the Centaur's RL-10 engines, engine ignition and cutoff, coasting for approximately 25 minutes, a second engine firing and cutoff, payload separation, Centaur course reversal, and finally the shutdown of all Centaur systems by ground-based operators.[240]

40-foot high, 20-foot diameter nitrogen-filled cold wall assembled around the Centaur in SPC No. 1
SPC Image No. 34: 1963-67186/NASA Glenn Research Center (1963)

After the AC-4 tests, the rocket was reharnessed again in the AC-8 configuration. In all, there were 20 to 30 test runs conducted over several years. Every aspect of the test was intended to be identical to actual flight, down to minutia like the ink used to mark wires.[241]

These studies verified the trustworthiness of Centaur's basic design and proved that the electrical system could perform during a two-burn flight in a space environment. The few design problems that were discovered, such as the electrical inverter and C-band transponder, were rectified before the Surveyor flights.[242] Among these was the recommendation not to use pressurized electronics canisters, and avoiding overheating by maintaining the minimal necessary power level.[243]

Propellant Management Studies: The SPC was also utilized for several liquid-hydrogen management tests such as the Weightlessness Analysis Sounding Probe (WASP) and Centaur hydrogen vent studies. The WASP was a two-stage sounding rocket designed by the NASA Lewis Spacecraft Technology Division to examine the control of liquid-hydrogen propellant during the periods between rocket firing, as on the two-burn Centaur flights. The WASP rocket would carry a transparent fuel tank and television cameras to film the behavior of the propellant during flight.[244]

WASP shroud jettison test set-up in the northeast corner of SPC No. 1
SPC Image No. 35: 1966-01846/NASA Glenn Research Center (1966)

The WASP's shroud underwent testing in the SPC in August 1964 and April 1966. On June 7, 1966 the WASP rocket was successfully launched off of Wallops Island with intentional sloshing of the liquid hydrogen.[245] The almost seven minutes of microgravity during freefall from 250,000 feet provided researchers enough data to launch AS-203 in July 1966.[246]

Hydrogen vent rig installed in SPC No. 2 following the failure of AC-4 flight due to sloshing
SPC Image No. 36: 1965-03932/NASA Glenn Research Center (1965)

The December 1964 Atlas/Centaur-4 and April 1966 Atlas/Centaur-8 missions were designed as propellant management studies. When the first engine burn ended on Atlas/Centaur-4, the liquid hydrogen sloshed forward resulting in the venting of some of the hydrogen in liquid rather than gas. The propellant's motion and resulting inability to maintain the vehicle's balance during venting off gases skewed the Centaur's trajectory causing additional liquid venting and tumbling. Approximately 90 percent of the liquid hydrogen was lost and the engines could not be restarted resulting in a failed mission. The failed Atlas/Centaur-4 mission demonstrated that engine shutoff, coasting, and restarting forces influenced the propellant's behavior. [247] [248]

Although research programs like Aerobee had previously studied the behavior of liquid hydrogen on scaled models, the AC-4 flight revealed the unique issues created by the forces associated with full-size propellant systems.[249] NASA Lewis researchers undertook a series of propellant management studies that resulted in several modifications for the Atlas/Centaur-8 flight. These included a baffle in the hydrogen tank to prevent sloshing, energy dissipaters, and a redesign of the vent system. The new system underwent extensive qualification and vent valve performance tests in the SPC No. 2.[250] On the AC-8 mission, the propellant was successfully managed and off-gasses were expelled without altering the rockets trajectory. [251]

Larger Shroud Testing: The SPC was also used for a series of Centaur and Agena nosecone separation tests for the Orbiting Astronomical Observatory (OAO) missions. The OAO satellites were designed by Goddard Space Flight Center to study and retrieve ultraviolet data on specific stars and galaxies which earthbound and even atmospheric telescopes could not view due to ozone absorption.[252] The OAO satellites were direct predecessors of the Hubble Telescope.[253]

The instrumentation and payload were covered by a nosecone as the rocket traveled through the atmosphere. The nosecone was then ejected once the vehicle was in space. SPC No. 2 was used because it was not necessary to simulate space since the nosecone separation occurred in the upper atmosphere. The existing exhausters were strong enough to reach that level.[254] In addition, the nose fairing was larger than the Surveyor fairings and the extra room in SPC No. 2 was needed.

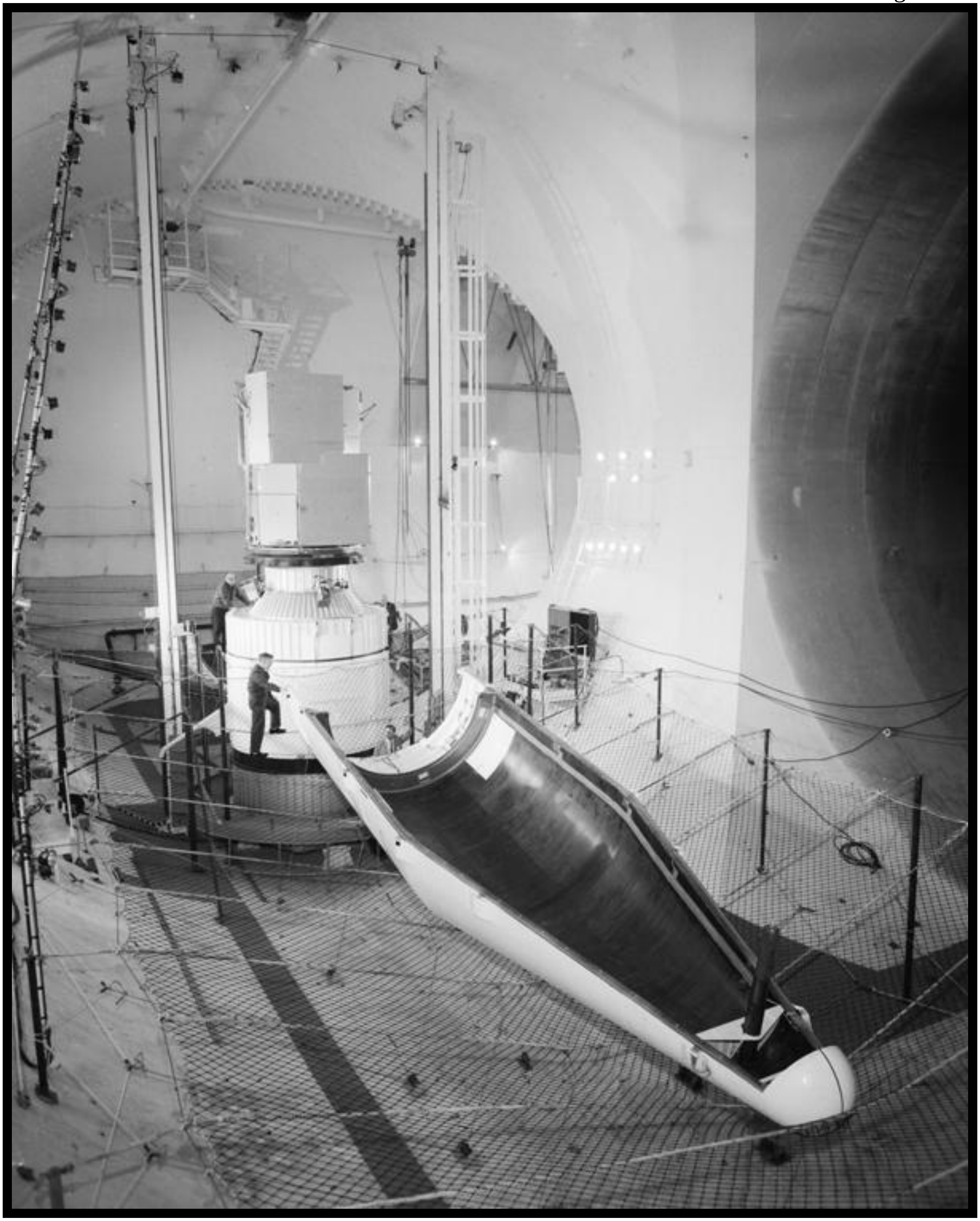
A steel base 10 feet in diameter was installed on the floor at the center of the chamber. A metal spacer was attached to the base, and a mock Centaur forward bulkhead attached to the spacer. The fairing and payload were then mounted to the forward bulkhead. A 50 by-30-foot nylon net was horizontally secured 11 feet above the chamber floor to catch the fairing halves after they were jettisoned.[255]

The first OAO satellite with its four experiments would be the heaviest payload yet carried by the Atlas Agena D.[256] During the summer of 1965 the shroud was tested three times in SPC No. 2 at altitudes of twenty miles. Accelerometers on the model and shroud provided researchers with data that could verify a successful separation during the actual launch.[257] The April 8, 1966 OAO-1 launch and separation went smoothly, but a battery failure caused the mission to fail within ninety minutes.[258]

After the failed first Agena-OAO mission it was decided to replace the Agena with the more powerful Centaur rocket. The basic Agena separation system and nose cone were retained, though. The 40-foot long modified nose fairing for the OAO-2 mission was 18 feet longer than the Atlas/Centaur Surveyor nose fairing, and it was jettisoned by a mechanical spring rather than gas thruster system.[259]

In April 1968 three OAO nose fairing setups were successfully jettisoned in SPC No. 2 at a simulated altitude of 90,000 feet.[260] OAO-2 was launched on Atlas/Centaur-16 on December 7, 1968 and after only a month, obtained over twenty times the amount of ultraviolet data from stars than all of the sounding rocket studies over the previous fifteen years combined.[261]

The next OAO mission, OAO-B, failed on November 30, 1970 when this nose fairing did not separate properly.[262] Although not used to test the shroud before the launch, the SPC was a principle element of the failure investigation. Tests in the SPC No. 2 during April 1971 led to a redesigned single piece fairing.[263] In April and May 1972 a full-scale version of this new OAO nosecone underwent a series of successful jettison tests in SPC No. 2. OAO-C or Copernicus, launched by AC-22 on August 21, 1972, remained an active observatory for eight years.[264]



Modified Agena shroud is tested with Centaur model in SPC No. 2 for OAO-2
SPC Image No. 37: 1968-01258/NASA Glenn Research Center *(1968)*

A redesigned single-piece shroud being tested in SPC No. 2 for use on the OAO-C mission
SPC Image No. 38: 1972-01417/NASA Glenn Research Center *(1972)*

C. Contemporary Vacuum Chamber Facilities

Vacuum Chamber Development: As humans began flying aircraft at greater elevations there were an increasing number of attempts to create ground-based facilities to test the behavior of both humans and aircraft components in altitude conditions. In general this simulation was accomplished by using vacuum chambers which reduce the air pressure inside the tank. These chambers are containers that achieve their low pressure or vacuum by using exhausters or pumps to remove the air and other gases. For basic altitude simulation air pressure and temperature have to be controlled, but humidity and air density may also be factors.

There are many different types and sizes of vacuum chambers used for a variety of different purposes. In the aerospace test facility field there are two basic variations. The first are smaller test cells used for altitude engine testing, such as the Propulsion Systems Laboratory at NASA Glenn Research Center or Arnold Engine Development Center's T cells. The second type is large vacuum chambers used to study flight hardware in a space environment. Examples of this are NASA Glenn's Space Power Facility and the Space Environment Simulation Laboratory at NASA's Marshall Space Flight Center. The AWT falls into the former category, and the SPC into the latter.

The first controlled demonstration of a vacuum dates back to Italy in 1643. After inverting a sealed Mercury tube and lowering it into a pool of mercury the Italian Evangelista Torricelli became the first person to maintain a vacuum. By observing that the mercury in the tube did not run out, he surmised that air in the tube had a weight and its exertion of pressure on the mercury in the pool kept the mercury in the tube elevated. This led to a series of bell jar vacuum experiments in the 1660s.[265]

With the advent of aircraft in the early 20th Century, manufacturers sought ways to test the engines in altitude conditions. The first altitude test beds in the 1910s were built at locations of high elevation. Frequent inclement weather and the relatively low altitudes dampered the effect of these facilities. The Zeppelin Works created at Friedrichshafen in south Germany may be the first vacuum chamber designed specifically to test aircraft engines. It was used for the engines for the Zeppelin airships.

Almost simultaneously, the National Bureau of Standards (NBS) also created an altitude chamber for engines in the United States. Hobart Cutler Dickinson was instrumental in the design of the Liberty aircraft engine at the onset of World War I and became head of the NBS aeronautical powerplant section. In this role, Dickinson designed and operated the nation's first altitude chamber for testing full-scale aircraft engines. The simulated 35,000 foot chamber was constructed by the NBS at the request of the NACA.[266] It made its first test run on December 26, 1917 with a Liberty 8 engine.[267]

In the 1930s the Italy city of Guidonia added a test bed that could simulate altitudes up to 16,000 feet. In 1933 the Germans created a similar test facility capable of partially simulating altitudes of 62,000 feet. A second facility at Rechlin also controlled the inlet temperature down to -60 degrees C and pressure altitude of 59,000 feet. The first real German altitude chamber was the Herbitus facility built in Munich during 1941. It was an actual tank in which refrigerated air was ducted to the engine inlet, the exhaust gas was cooled, and evacuated to a pressure altitude of 36,000 feet. At the end of the war, the facility was seized by American troops. The Herbitus was considered the first altitude test bed for jet engines. It was dismantled and reassembled at the Arnold Engineering Development Center (AEDC).

<u>NACA Altitude Chambers:</u> The NACA's Aircraft Engine Research Laboratory in Cleveland, Ohio used the vacuum concept to lower the air pressure to simulate high altitudes in its Altitude Wind Tunnel (AWT) in 1944.[22] The wind tunnel used exhausters to create a vacuum-like atmosphere and remove combustion gases. The AWT could operate full-scale engines in conditions that replicated the speed, altitude, and temperature of actual flight.

Two altitude test cells were built inside the Engine Research Building during the mid-1940s to alleviate the AWT's workload. This facility, referred to as the Four Burner Area, contained two static chambers into which full-size engines could be installed and run at altitudes up to 50,000 feet and temperatures ranging from 200 to -70° F. An even larger pair of test chambers, the Propulsion Systems Laboratory (PSL), was added in 1952. Similar facilities, such as the Ordnance Aerophysics Laboratory in Texas were built in the 1950s.

The late 1950s brought not only increasingly larger and faster engines, but more importantly the advent of the space age. Initial missions in the late 1950s revealed the behavior of engines, flight systems, and hardware was affected by the conditions encountered in space. The AWT's altitude simulation was used during 1959 and 1960 for a number of Project Mercury tests at pressure altitudes up 100,000 feet. These did not use the tunnel's airflow, just its 51-foot diameter and 163-foot long western leg and the exhauster pumps.

In 1960 McDonnell created a 30-foot diameter vacuum chamber at its St. Louis location. The effort, referred to as Project Orbit, subjected the Mercury capsule to simulated missions in the chamber altitudes up to 40,000 feet. Soon afterwards a more powerful altitude test chamber was constructed in Hanger S at Cape Canaveral. When completed, altitude pressure would simulate 225,000 feet. The chamber, a vertical cylinder with domed ends, was 12 feet in diameter and 14 feet high. The chamber was designed to allow a partial spacecraft functional check in a near-vacuum environment. Construction completed in April 1960. The first simulated orbital mission, with the Mercury spacecraft in the altitude chamber, was conducted on April 1961.[268] These were useful tools but limited by their size.

In 1960 it was decided to increase the AWT's vacuum capabilities and permanently construct two test chambers within the tunnel shell—one capable of simulating the altitudes of outer space, the other of earth's upper atmosphere. The facility was renamed the Space Power Chambers (SPC). The space chamber was originally intended to study a full-scale SNAP-8 nuclear space power conversion system.

At the time there were no tanks of that size which could produce such a deep vacuum in the U.S. By the end of 1962, when the SPC was completed, there were 9 large vacuum chambers. Many

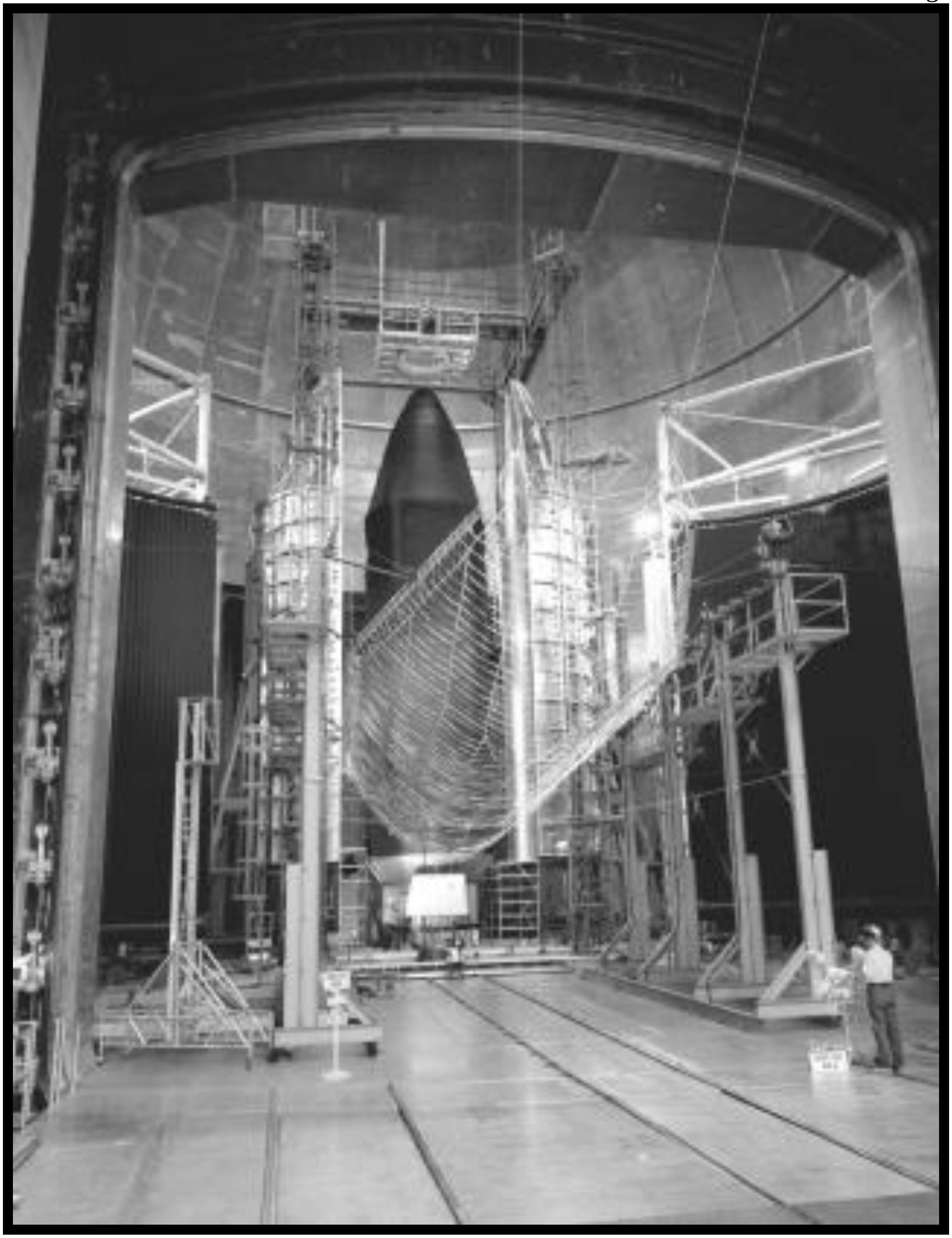
[22] For information on the AWT, see the first section this document.

others would emerge by 1965. Although larger chambers capable of deeper vacuums would later be constructed, the rapid conversion of the AWT into a space tank allowed the 31-foot diameter, 100-foot long tank to play a vital role in the early years of the space program.

There were two major tanks that became operational in 1965, the Aerospace Environmental Chamber known as Mark I at the AEDC and the two chambers in the Space Environment Simulation Laboratory (SESL) at what is today the Johnson Space Center. The 35-foot diameter by 65-foot long Mark I tank was slightly wider than the SPC but not as long. The 65-foot diameter and 120-foot tall Chamber A at the SESL was built specifically to test the Apollo capsule. It was significantly larger than the SPC and could create high altitudes. Like Mark I, the SESL's Chamber B was wider than the SPC but not as long.[269]

At Lewis in the 1960s, Director Abe Silverstein continued to seek better facilities to test flight hardware and propulsion systems in space environments. An auxiliary site called Plum Brook Station was used to build a test reactor and a number of large space test facilities. The two most impressive were the B-2 Space Propulsion Facility (now a National Historic Landmark) and the massive Space Power Facility. The Space Power Facility (SPF) remains the world's largest thermal vacuum chamber, measuring 100 feet in diameter and 122 feet high. It has been used extensively to test rocket payload fairings, various systems for the International Space Station, and planetary landing systems such as those developed for the Mars Exploration Rovers. In March 2007, NASA announced SPF would be used to perform integrated environmental testing of the Orion Crew Exploration Vehicle (CEV). The tests will simulate environmental conditions such as those the Orion will experience during launch, in-orbit operations and re-entry.[270]

In 1998, Hughes Space and Communications Company added a 63,000-cubic-foot, dual-capacity thermal vacuum chamber to its massive Integrated Satellite Factory in Los Angeles. The facility can conduct four thermal vacuum tests at space altitudes, five near-field antenna tests, and two thermal stress tests.[271]



View inside Space Power Facility at NASA Glenn's auxiliary Plum Brook Station
SPC Image No. 39: 1973-03951/NASA Glenn Research Center *(1973)*

Part II. Architectural Information

The Space Power Chambers (SPC) contained the center's first and only large vacuum chamber for testing flight hardware from 1963 until it was superseded by the Space Power Facility at Plum Brook Station in 1969. The facility was located inside the former Altitude Wind Tunnel (AWT) which was among the first group of structures built at the center in the 1940s. The SPC contained two altitude test chambers within the tunnel shell.

The SPC's supporting infrastructure included the Shop and Office Building, Vacuum Pump House, Refrigeration Building, and Cooling Tower No. 1. All of these structures were built in the immediate vicinity of the facility.[23] The SPC's central location allowed it to easily work in conjunction with several other facilities and buildings, including the Hangar, Engine Research Building, and Propulsion Systems Laboratory.

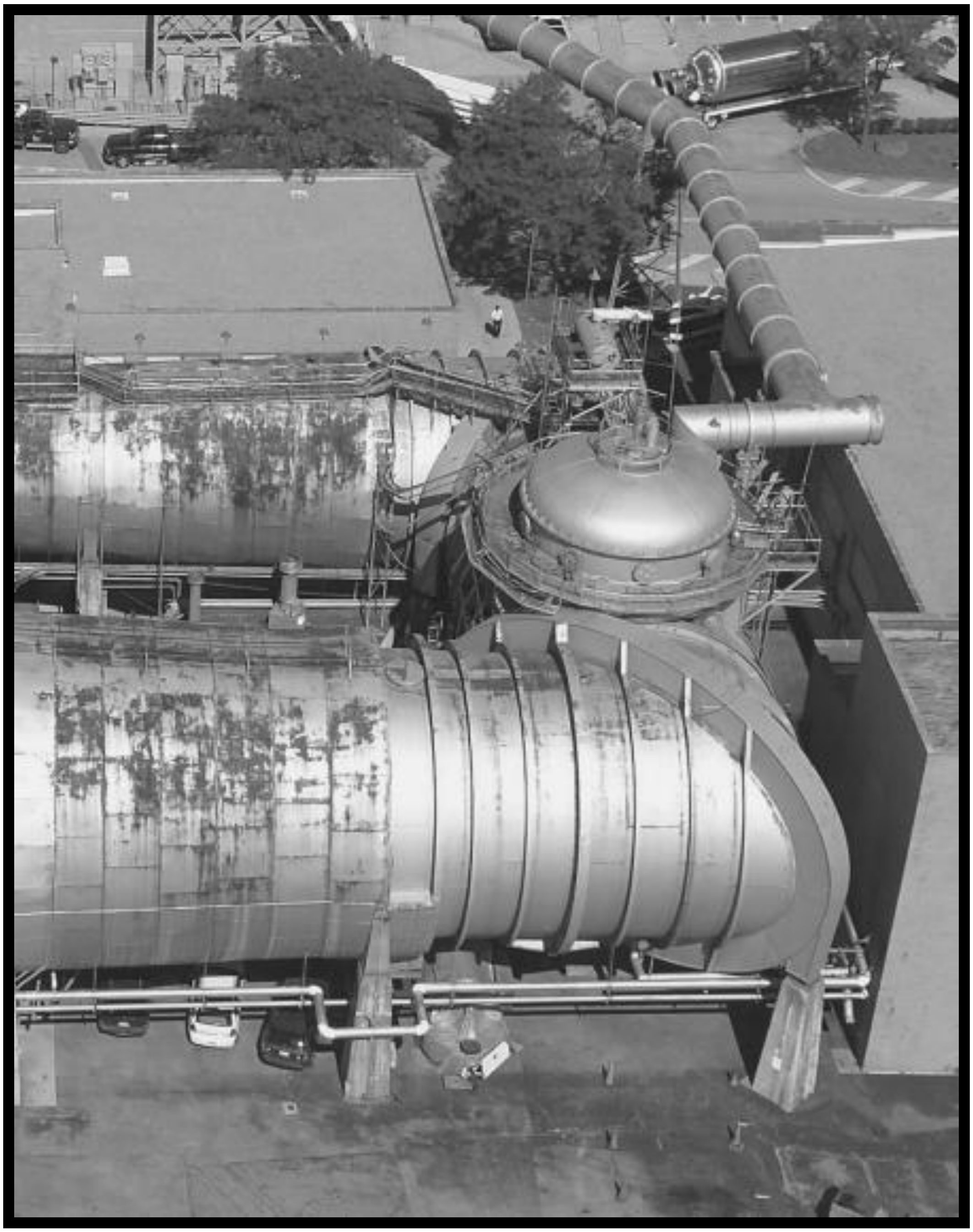
The tunnel which contains the two chambers was a massive rectangular structure 263 feet long on the north and south legs, and 121 feet long on the east and west sides. The 20 foot diameter former tunnel test section, which served as the main entranceway to the two test chambers, was contained in the rear test chamber room of the Shop and Office Building. The courtyard inside the tunnel loop was approximately 40 feet wide at the east end, 18 feet at the west end, and 168 feet long.[272]

View from south of the SPC complex in the former Altitude Wind Tunnel
SPC Image No. 40: 2005-01493/NASA Glenn Research Center *(2005)*

[23] For additional information see the Support Buildings section of this report

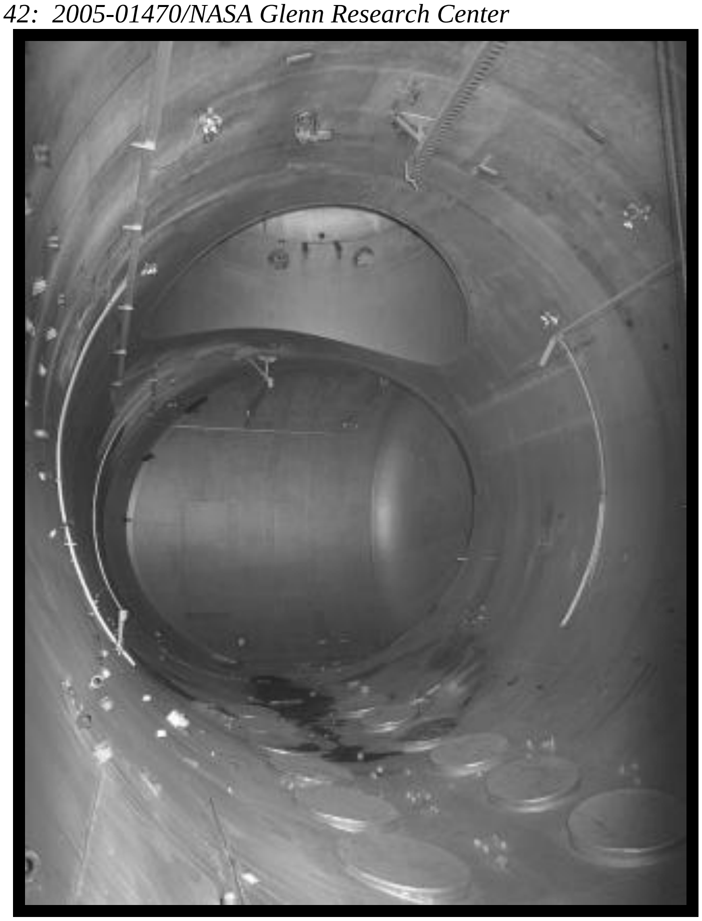
A. Space Power Chamber No. 1:

The high-vacuum SPC No. 1 was created in the east leg of the tunnel and had a 70,000 cubic foot internal volume. The 100-foot long chamber was 31 feet in diameter at the southeast end and 27 feet diameter at the northeast end.[273] A 22.5-foot diameter cylindrical extension with a removable dome was inserted in the ceiling to create a 45-foot vertical space within the chamber.[274]



View from south of SPC No. 1 in the east leg of the former wind tunnel
SPC Image No. 41: 2007-02580/NASA Glenn Research Center *(2005)*

View from west of SPC No. 1 extension and dome
SPC Image No. 42: 2005-01470/NASA Glenn Research Center (2005)



View south of interior of SPC No. 1 with opening for dome at top and pump penetrations on floor
SPC Image No.43: 2005-01657/NASA Glenn Research Center (2005)

Shell: The original tunnel shell consisted of a 1-inch thick inner steel shell with fiberglass insulation over it and a thinner outer steel covering. The outer covering and insulation were permanently removed during the creation of SPC No. 1. The inner steel alloy shell was rewelded and sealed to withstand the decreased pressures the chamber would be subjected to. The two large corner rings and 31 tunnel support rings jutted out from the shell.

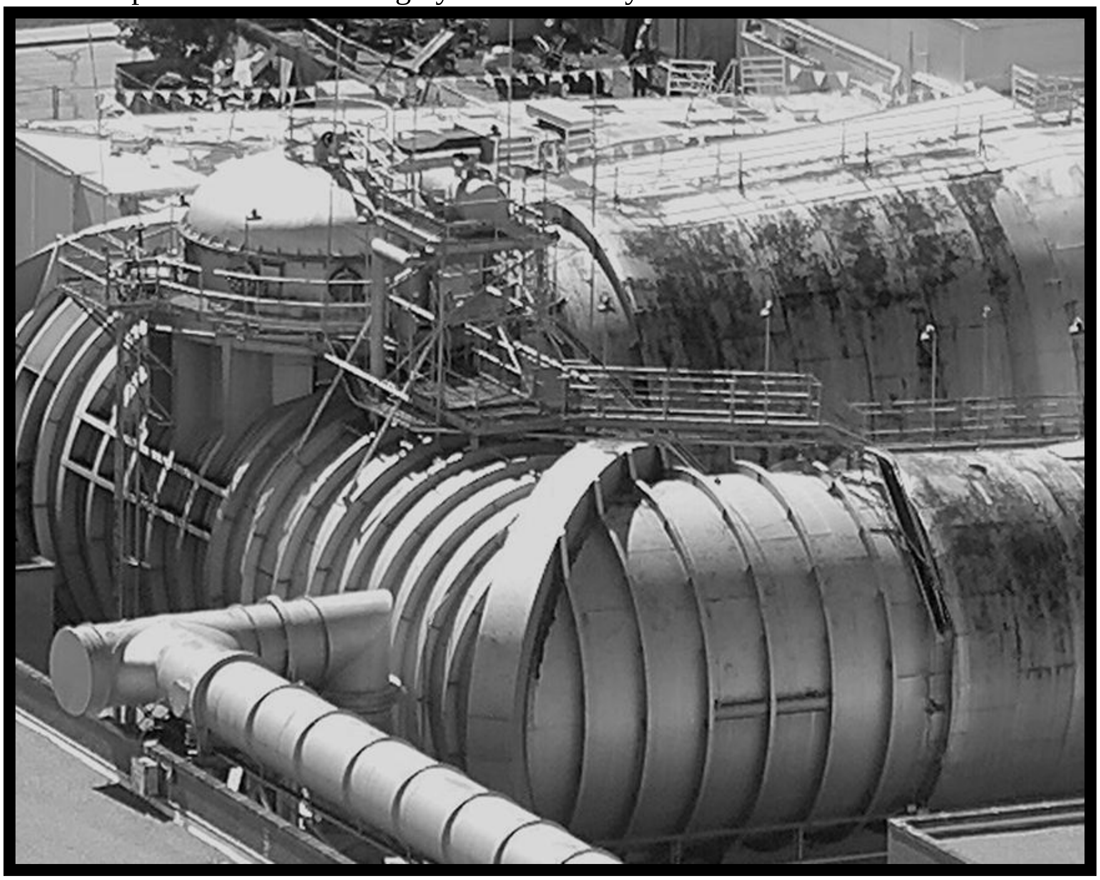
The sealing of the SPC No. 1 was particularly important to create the vacuum comparable to that found in space. One of the most pressing problems during the creation of the tank was the poor welds that were made during the hurried World War II construction of the tunnel. Small plastic bags were placed over each weld and filled with helium, and a helium leak detector was used to analyze how much helium leaked through each of the welds and penetrations.[275] The entire SPC No. 1 shell was rewelded at a considerable expense.

The coating of the tunnel with a protective grey paint appears to have ceased in the mid-1990s. SPC No. 1's shell appears to have suffered less rust damage than the thin protective steel covering the rest of the facility.

SPC No. 1 shell to the right with original tunnel outer shell to the left showing heavy rust damage
SPC Image No.44: 2005-01484/NASA Glenn Research Center (2005)

Dome and Extension: The dome, installed between 78th and 83rd ring on the eastern leg of the tunnel, provided a 45-foot high area inside the chamber.[276] The top of the dome was elevated 17 feet 6 1/8 inches from the tunnel shell. The dome sat atop a vertical base which extended from the top of the tunnel. This steel base had steel fins radiating from its perimeter that corresponded to the tunnel's support rings. Around the top of the base was a steel support band.[277]

The exterior sides of the dome contained nine 32-inch diameter circular portals which extended 1.5 feet outside the dome.[278] Two of the dome's ports permitted electrical connections to heater panels inside the chamber.[279] The lower panels were powered through ports near the bottom of the chamber. The wires from the dome were guided the chamber and into the SPC No. 1 control room in the Shop and Office Building by two cable trays.



View from northeast of SPC No. 1 with its extension, dome, and surrounding walkways
SPC Image No.45: 2005-01490/NASA Glenn Research Center (2005)

An elevated catwalk erected around the dome allowed access to the instrumentation portals and cable trays. From this catwalk, a small ladder and four metal steps metal stairway was built to allow access from the dome base to the top of the cap. A small fixed ladder connected the catwalk to a grated foot bridge running northwest. This bridge joined the existing walkway along the top of the tunnel's northeast leg. This A series of light fixtures were placed along the catwalk and pathway. The walkway that originally ran along this portion of the tunnel was removed during the conversion to the vacuum chamber.

View from north of SPC No. 1 dome showing its base, instrumentation portals, and lid
SPC Image No.46: 1963-56905/NASA Glenn Research Center (1963)

View from east of lid being removed by crane from SPC No. 1 dome
SPC Image No. 47: 1964-67907/NASA Glenn Research Center (1964)

The dome was capped by a 22.5-foot diameter lid that was approximately 4.5 feet high.[280] The lid had a flat circular top area with a vent pipe and a sealed stove pipe in the center. There were also three eyehooks to secure the cables to for lifting. This top area was surrounded by metal handrails. There were four grated steps with handrails leading from the edge of the lid to its top. The top area was also enclosed by handrails.[281]

When the lid was in place a .25-inch ring around the lid was welded to a .25-inch ring around the chamber opening. This permitted both a solid seal and the ability to break the seal when the cap had to be removed.[282]

SPC No. 1 lid being lowered to the ground by a crane
SPC Image No. 48 : 1964-67909/NASA Glenn Research Center (1964)

View north of SPC No. 1 interior with the extension and dome at the to and cable tray along wall
SPC Image No. 49: 2005-01479/NASA Glenn Research Center (2005)

Interior Walls: The interior walls were primarily smooth with few obstructions or penetrations besides the dome in the ceiling and the 10 vents in the floor for the diffusion pumps. The corner rings were flat surfaces which smoothed relatively flush with the walls. There were a series of flood light fixtures mounted along the upper portions of the walls with cable trays just below. The floor possessed a large number of fixed eyehooks and other fittings that were used for various test setups in the 1960s. The ceiling contained a monorail crane track down the middle of it. The former wind tunnel drive shaft penetration that had been sealed in 1961 was almost flush with the eastern wall.

During the conversion process from wind tunnel to altitude chamber, the rust, scale, and engine exhaust pollutants were sandblasted from the interior of the tunnel. The new chamber was then sealed with a double-coat of aluminum paint.[283]

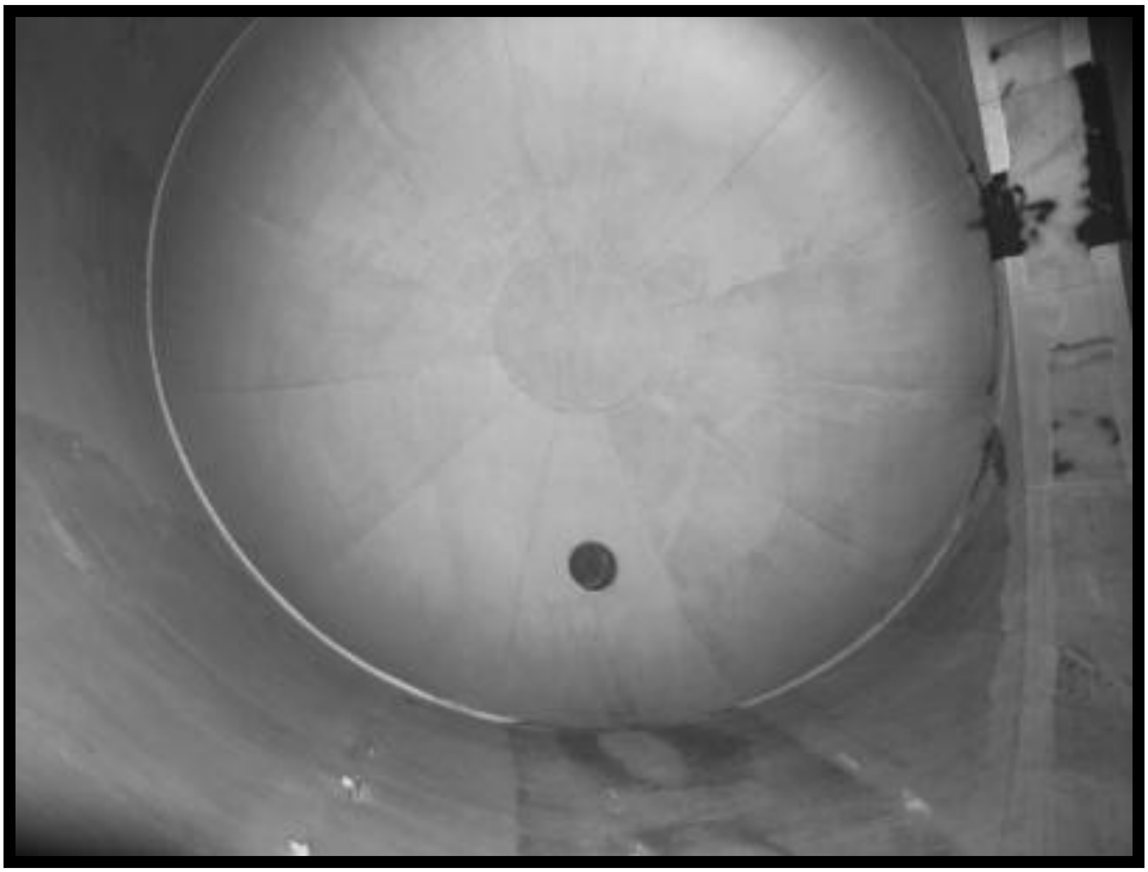
In 2005 the walls and ceiling showed some signs of rust, but were in fairly good condition. The floor, however, suffered a great deal of rust and water damage especially underneath the dome. This was caused from rain entering through the unsealed access portals around the dome.

View of the SPC No. 1 dome and lid from inside the chamber
SPC Image No. 50: 2005-01649/NASA Glenn Research Center (2005)

View from south of SPC No. 1 floor showing water damage and numerous fittings from tests
SPC Image No. 51: 2005-01644/NASA Glenn Research Center (2005)

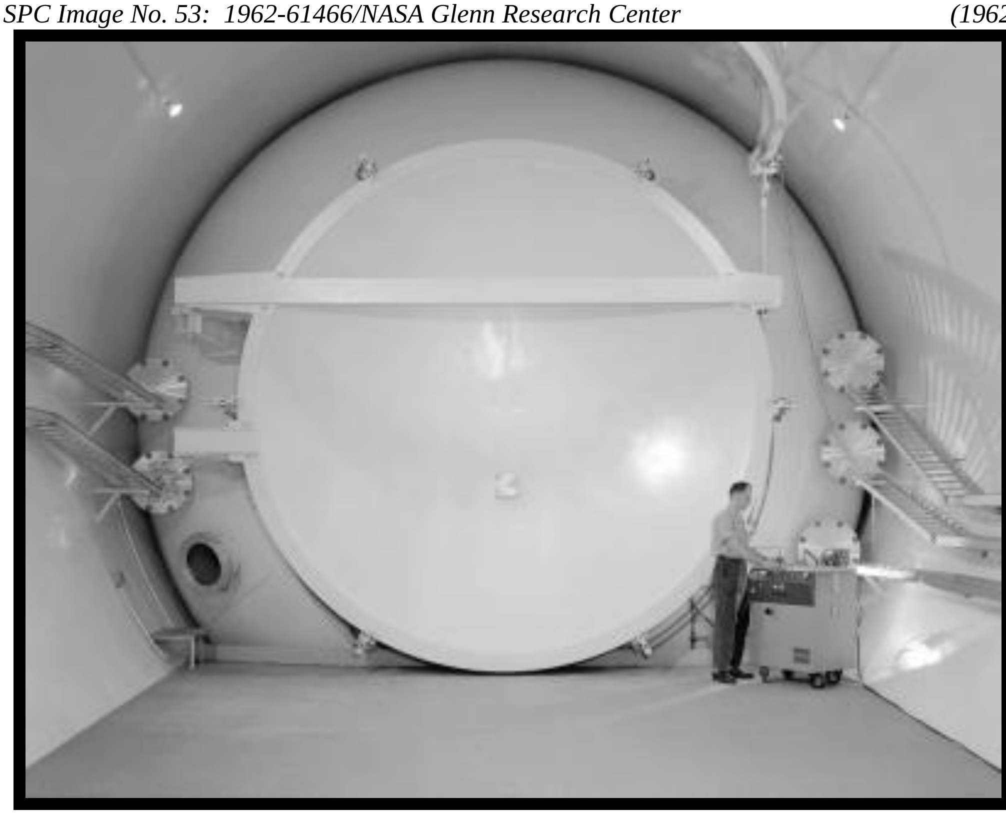
Bulkheads: SPC No. 1 was sealed from the rest of the tunnel by bulkheads at the southwest and northwest portions of the chamber. The larger, 31-foot diameter convex at the southwest, consisted of a circular metal plate at its center with 12 triangular pieces of steel radiating from it. A 24-inch diameter viewing port was located several feet below the center plate.[284]

The 27-foot diameter bulkhead at the north end of the chamber contained three access ports on the on each side and a 15-foot diameter door in the middle. This door was braced by two horizontal metal beams across the upper portion of the door and had dual O-ring seals.[285] An overhead pulley with a thick steel chain was used to open and shut the door. Nitrogen inlet and outlet connections were installed on chevron baffle chambers.[286]



View westward of 31-foot diameter bulkhead at south end of SPC No. 1
SPC Image No. 52: 2007-02568/NASA Glenn Research Center *(2005)*

Westward view from in SPC No. 1 of bulkhead with swinging door in center and ports on sides
SPC Image No. 53: 1962-61466/NASA Glenn Research Center (1962)

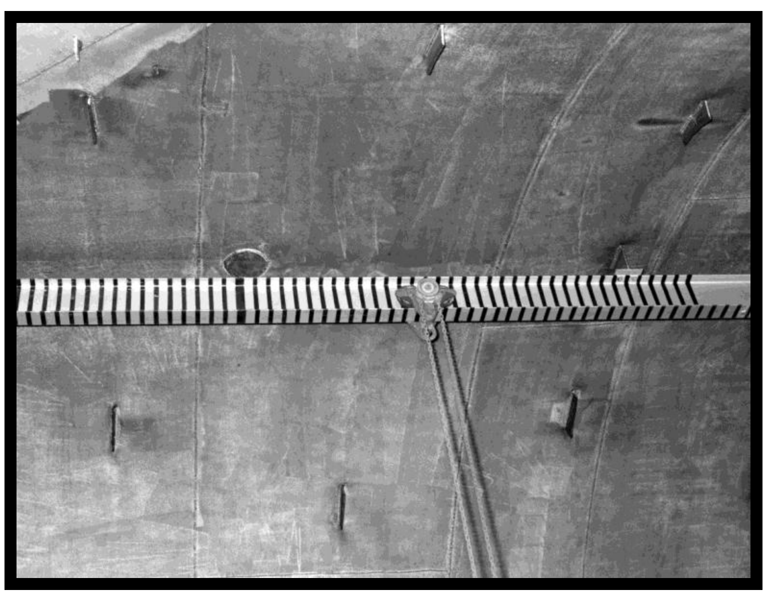


Eastward view from former test section of SPC No. 1 bulkhead with its door closed
SPC Image No. 54: 1962-60341/NASA Glenn Research Center (1962)

Close-up of one of instrumentation ports in the north SPC No. 1 bulkhead
SPC Image No. 55: 2005-01664/NASA Glenn Research Center (2005)

The access ports were aligned vertically on each side of the door. The north side had three 18-inch instrumentation ports with aluminum face plates. The south side had two of the same and an 18-inch diameter viewing port with a polished plate glass face. The plates were buried between 12 and 27 inches into the bulkhead away from the chamber.[287]

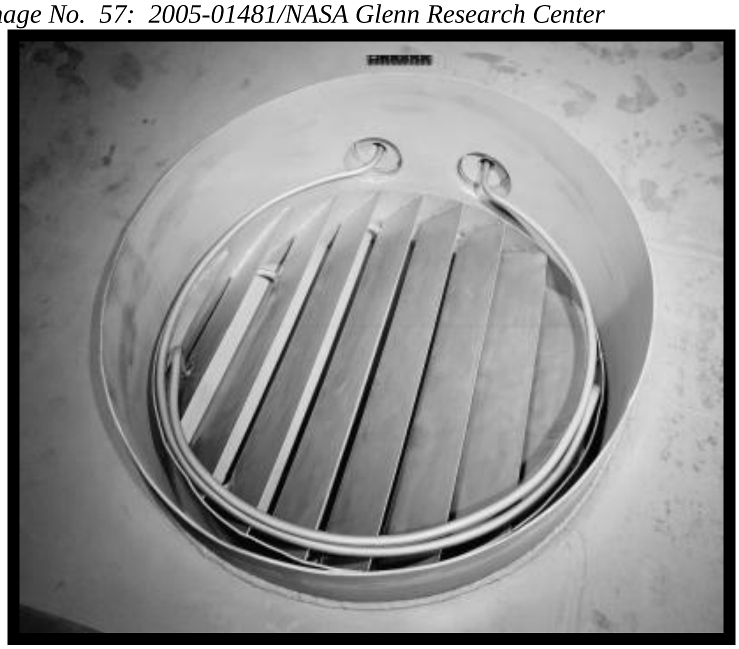
Crane: An overhead 4000-pound rail crane was installed in the SPC No. 1. It ran west a short distance in the northwest corner, then curved and ran southward along the chamber ceiling to the southwest corner.[288]



4000 pound monorail crane along center of SPC No. 1 ceiling
SPC Image No.56: 2005/01661/NASA Glenn Research Center (2005)

Because the 15-foot diameter access door in the northern bulkhead, a platform with steps had to be constructed inside the chamber. This platform was approximately 5 feet above the floor and stretched the entire width of the bulkhead. The stairs had dual handrails and the platform had posts across the front with chain as a railing.

View of platform inside SPC No. 1 providing access to the doorway in the bulkhead
SPC Image No. 57: 2005-01481/NASA Glenn Research Center (2005)



Close-up of one of ten diffusion pump openings in the floor of SPC No. 1
SPC Image No. 58: 1962-61465/NASA Glenn Research Center (1962)

Vacuum System: The vacuum system was the primary element in SPC No. 1's ability to simulate a space environment. During the conversion of the tunnel to a space tank, the existing pumping system was replaced by a new oil diffusion-based system. Ten diffusion pumps and several roughing pumps were installed in the new Vacuum Pump House building underneath the SPC No. 1. The empty chamber could to be evacuated to 10 to minus 6.

The vacuum was brought down slowly in several phases to prevent excessive air flow over the pumps. The center's central exhauster system could evacuate the tank to 100,000 feet pressure altitude in about fifteen minutes. Then two piston pumps simultaneously remove 12.5 cubic feet of air per second during the roughing stage.[289] A rotary positive displacement pump then removes 500 cubic feet per second. The final vacuum is pulled down by the ten 32-inch diameter oil diffusion pumps which could remove 17,650 cubic feet air per second. The entire process took about 24 hours, but the chamber could be returned to sea level almost instantly using a gaseous nitrogen system.[290]

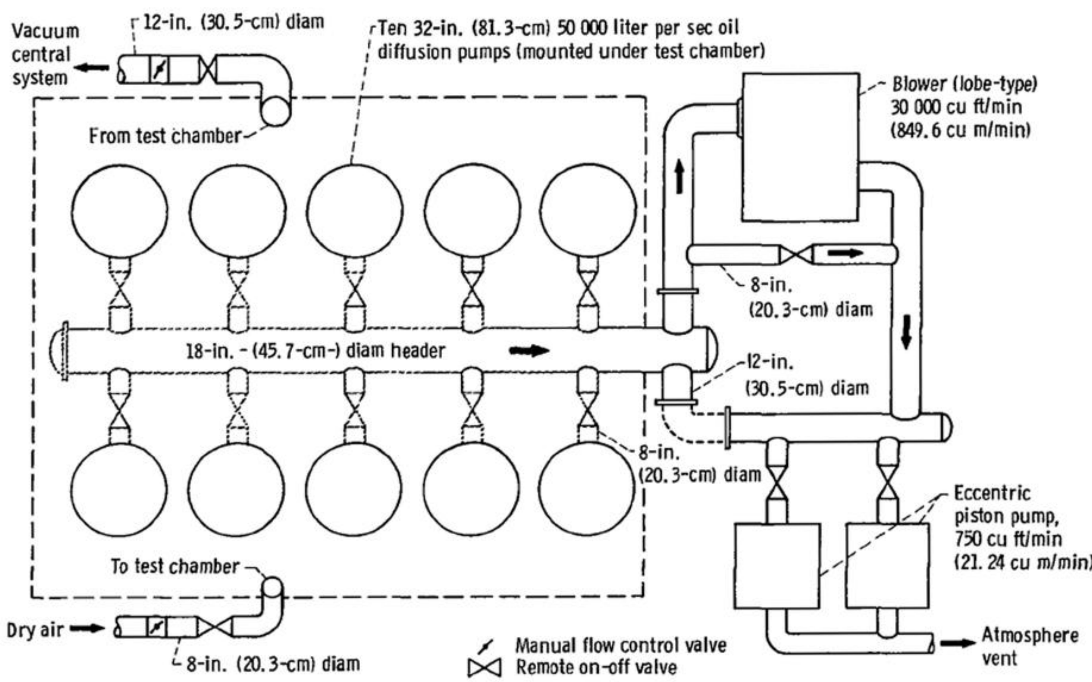
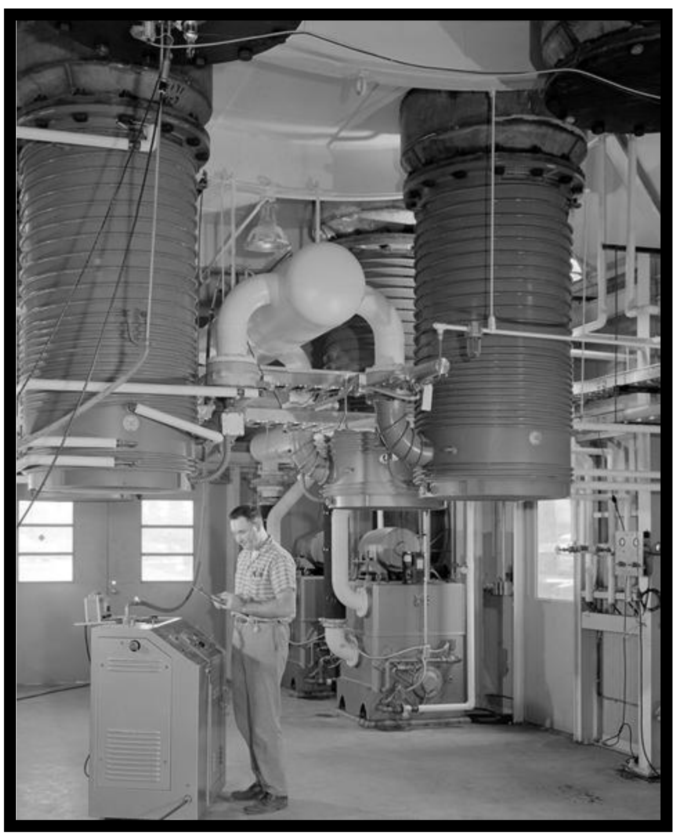


Figure 20. - Test chamber vacuum system and dry air bleed system.

Test chamber vacuum system and dry air bleed system
SPC Image No.59: NASA TM-X-1929 Figure 20/NASA Glenn Research Center

Diffusion pump openings in SPC No. 1 during its conversion to vacuum tank
SPC Image No. 60: 1961-58576/NASA Glenn Research Center (1961)



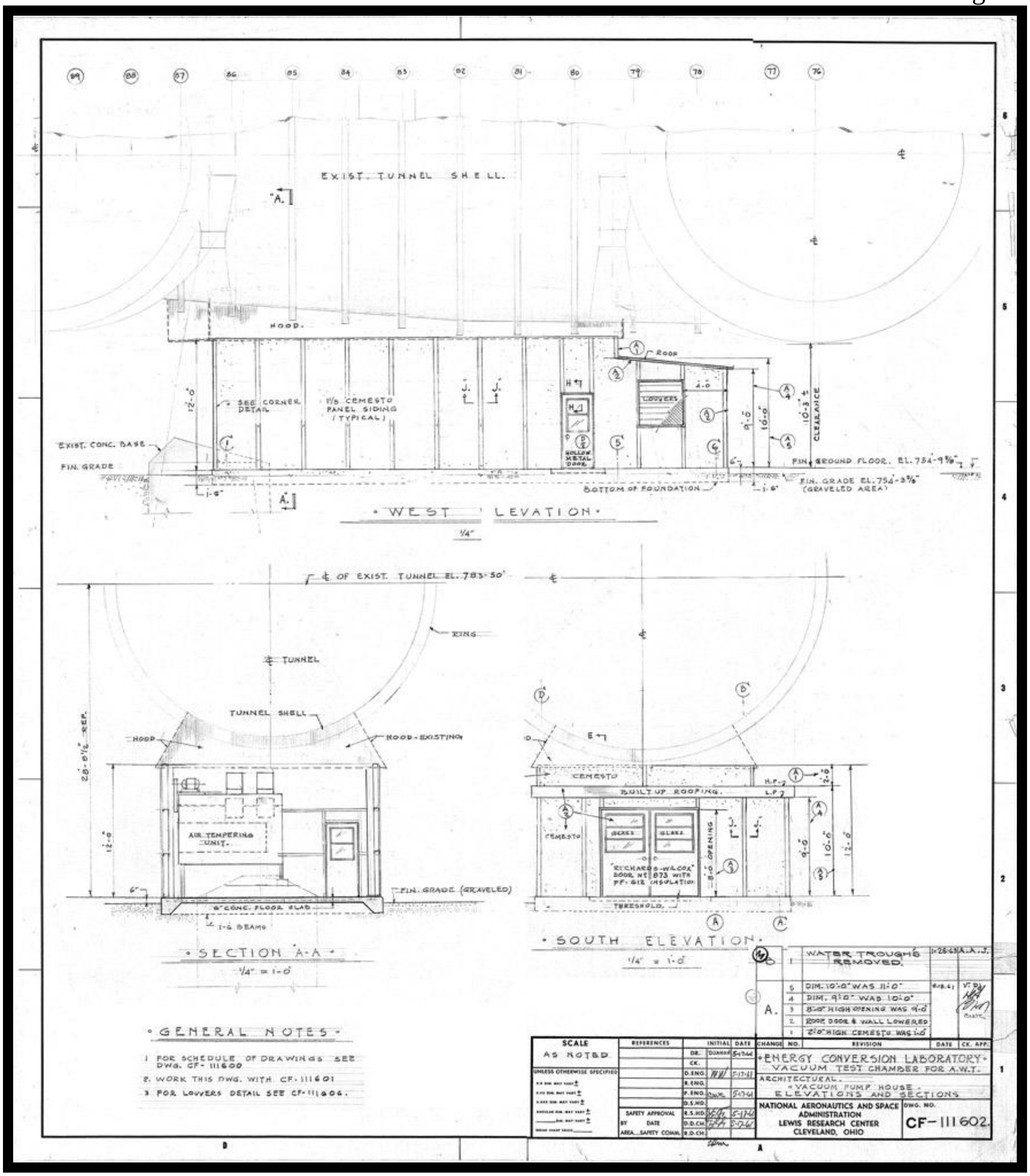
Interior view from the north of Vacuum Pump House and its diffusion pumps below SPC No. 1
SPC Image No. 61: 1962-60344/NASA Glenn Research Center (1962)

View from southeast of rear of Vacuum Pump House beneath SPC No. 1
SPC Image No. 62: 2007-00406/NASA Glenn Research Center (2007)

<u>Vacuum Pump House</u>: The new pumps were housed in a 12-foot high, 46-foot 7/8-inches long, and 20-foot 1 inch wide structure built directly underneath SPC No. 1. The main portion of this Vacuum Pump House actually used the bottom of the chamber as its roof. The front north side had a sloping roof 9-foot high at its lower edge. The east side of the building had a pedestrian door near the center and ventilation louvers further northward. The west side possessed identical louvers. The north side had a single pedestrian door and rectangular louvers. The south end had double set of pedestrian doors. A hood connected the sides of the main structure to the bottom of the wind tunnel.[291]

The pump house had ten CVC PMC-50,000 oil diffusion pumps lined in pairs. An 18-inch diameter pipe joined the pumps and connected them to a Roots 10x24 vacuum (blower) booster pump in the northwest corner of the building and two Stokes 3/2 H mechanical vacuum pumps in the northeast corner.[292]

Since the chambers have been idle, this structure has been used for storage by the Educational Services Division. It was demolished during the demolition of the tunnel in 2009.



Vacuum Pump House elevations and sections drawings
Support Image No. 63: CF-111602/NASA Glenn Research Center *(1961)*

Construction of Vacuum Pump House beneath SPC No. 1
SPC Image No. 64: 1961-57859/NASA Glenn Research Center (1961)

View from northeast of exterior of the Vacuum Pump House under SPC No. 1
SPC Image No. 65: 2007-00407/NASA Glenn Research Center (2007)

B. Centaur Systems Test Setup

Besides adding the dome and extension to the SPC No. 1 vacuum tank there were several other modifications made specifically for the environmental testing of the full-sized Centaur rocket. These included components to simulate the temperatures of space, general set-up and work equipment, and infrastructure to power and operate the spacecraft.

Centaur 6A Rocket: The Centaur that was used for the SPC No. 1 tests was an early 6A model with thinner fuel tanks than later versions. This Centaur was used for static engine tests in Sycamore Canyon, California and launch site integration tests a Cape Kennedy. It was originally intended to be used for the follow-up to the Atlas/Centaur-2 flight, but a rehab of the launch pad delayed the launch.[293] The Centaur was removed and transported to Cleveland and another Centaur was eventually launched.

The 28.5-foot long and 10-foot diameter Centaur 6A had two Pratt & Whitney RL-10 15,000-pound thrust engines which rotated to steer the rocket. During the coast periods, hydrogen peroxide engines on the aft side maneuvered the rocket.[294] The Centaur had two balloon-type propellant tanks. The electronics and control systems were at the forward section of the rocket, while the mechanical and propulsion systems were near the rear. The electronics package was located just below the payload and above the Centaur's forward bulkhead. A fiberglass fairing shielded the electronics and payload during the launch. The cryogenic propellant tank was shielded by insulation panels until the spacecraft exits the atmosphere.

Centaur 6A rocket readied in SPC shop before testing in SPC No. 1
SPC Image No. 66: 1963-66504/NASA Glenn Research Center (1963)

Stand which supported the Centaur rocket being lifted into SPC No. 1
SPC Image No.67: 1964-67903/NASA Glenn Research Center (1964)

Platform: The Centaur rested in an approximately 9-foot tall triangular stand that sat on the chamber floor below the dome. The stand had a circular metal band approximately 18 inches wide in the middle into which the rocket was inserted. This band was supported at its edges by steel beams arranged in two triangular shapes. This entire structure was elevated approximately 6 feet by three struts. Two stretch towers inside the chamber supported the Centaur vertically and kept the spacecraft from collapsing on itself.

A large moveable platform was constructed along the floor of the SPC No. 1 that allowed technicians access to the Centaur setup. The circular platform was 5-foot 9-inches in diameter that surrounded the vertically standing Centaur.[295] This ran on the metal 30-inch high rails along the east and west walls of the chamber.[296]

Cold Wall: A large liquid nitrogen cooled copper baffle was erected around the entire Centaur set-up to simulate the cold temperatures of outer space. The radiant heat absorption device was designed specifically for these tests. The canister-like cold wall was 20 feet in diameter and 42 feet high rising into the dome. The dome lid actually contained the top of the baffle. The baffle had liquid nitrogen filled ribs that ran vertically the length of the Centaur and was painted black on the interior to attract heat.[297] These bottles had to be welded together using the new Heliarc technique, which involved welding on copper. The success of this process was crucial since any nitrogen leaks would break the desired vacuum level.[298]

A thermal-siphon was used to draw cryogenic liquid nitrogen into its vertical ribs. The liquid nitrogen was stored in three 7,000 gallon tanks stored outside of the chamber and pumped into the baffle through the penetrations in the dome and near the rocket's base. The pressurization was remotely managed from the control room. The nitrogen flowed through a separation tank which contained a float switch that automatically kept the cold wall filled. A basin was placed underneath the cold wall to trap any cryogenic fuels that leaked from the wall or engines.[299]

Nitrogen separation tank set-up to left of the dome supplied the cold wall inside with coolant
SPC Image No. 68: 1967-00181/NASA Glenn Research Center (1967)

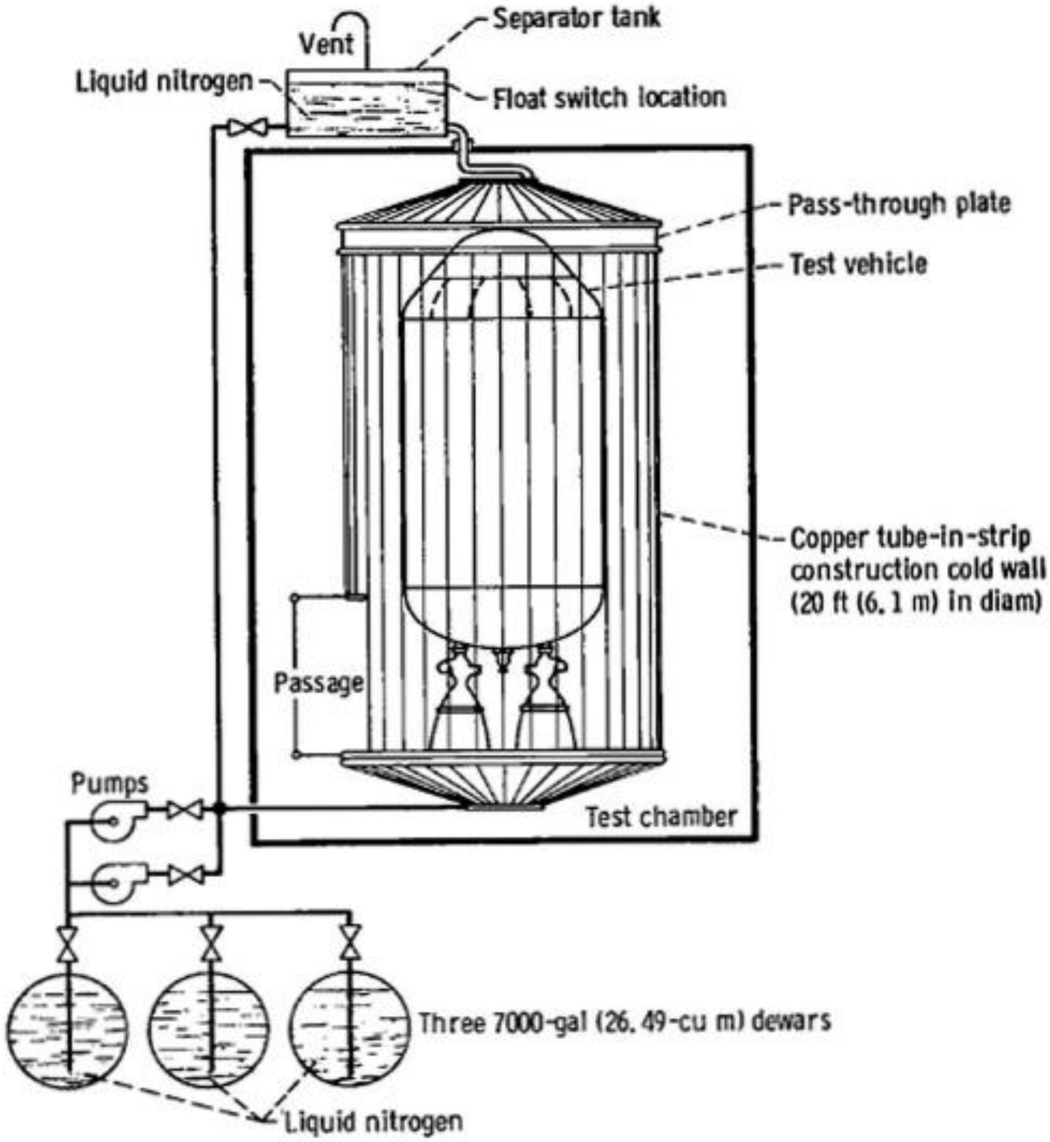
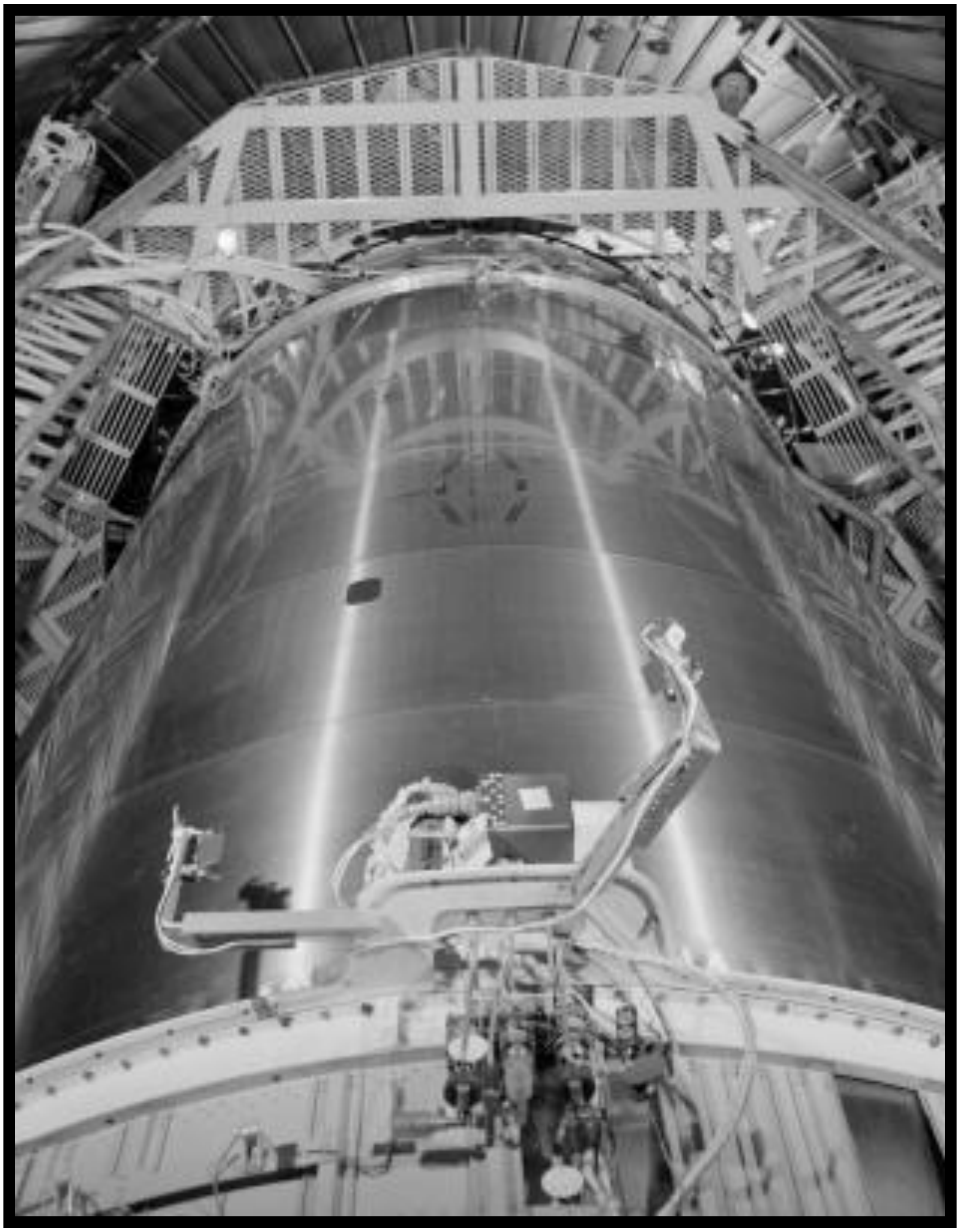


Figure 10. - Radiant heat absorption system (cold wall).

Test Method

Diagram explaining the nitrogen cold wall placed around the Centaur to create cryogenic temperatures
SPC Image No.69: NASA TM-X-1929 Figure 10/NASA Glenn Research Center

Heater Panels: A radiant heater system was also designed specifically for these Centaur tests to simulate the effect of the sun's heat on the rocket systems. Certain lamps could be turned on at different times to recreate the changing areas of the rocket exposed sunlight during a mission. Six sectors of 500-watt tungsten-iodine lamps were arranged around the Centaur to simulate solar radiation. Four of these arrays were on the upper end of the Centaur—one contained 23 lamps at the payload adaptor and three with 91 lamps which surrounded the entire forward portion of the vehicle. Two arrays with 145 lamps were located near the RL-10 engines.[300]

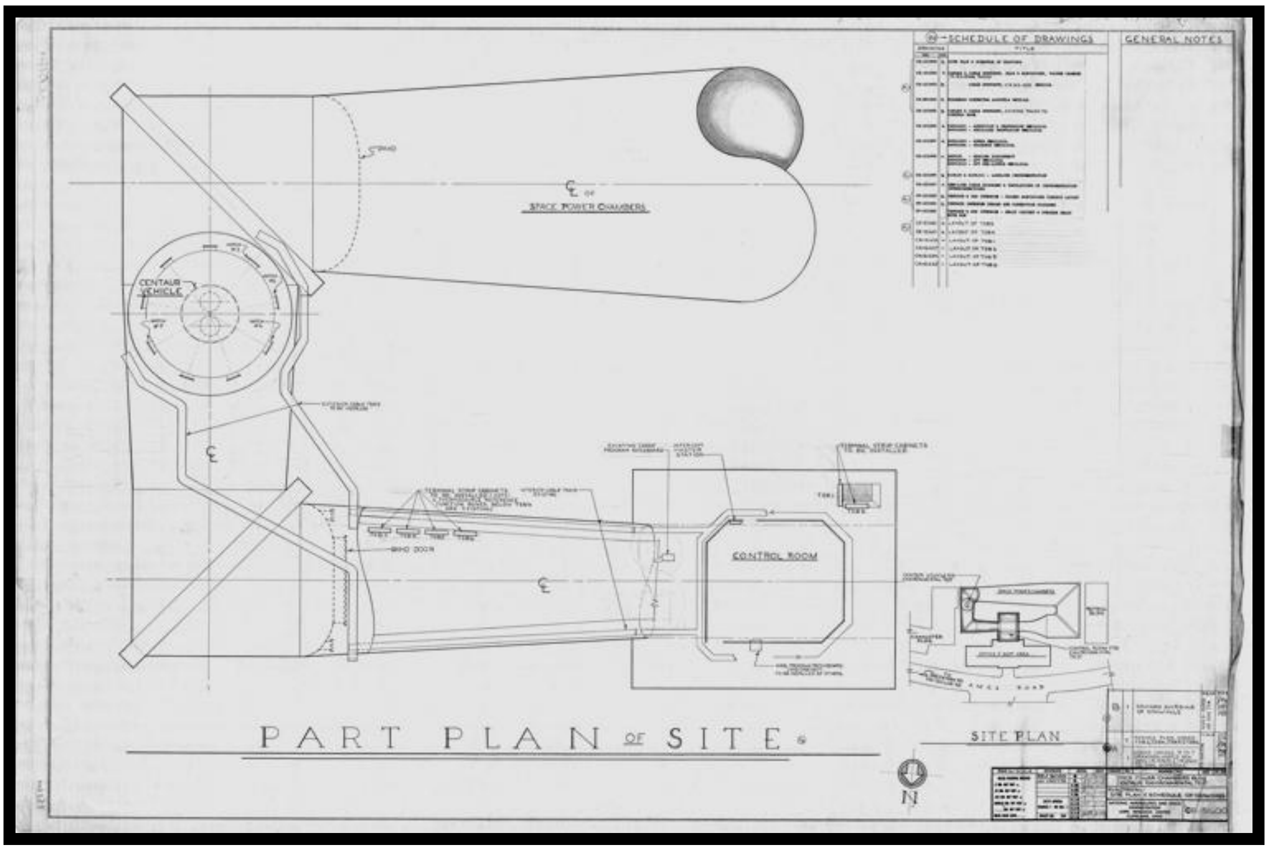


View up side of the Centaur showing a group of tungsten lamps in foreground
SPC Image No.70: 1967-00180/NASA Glenn Research Center (1967)

Telemetry: The telemetry for the Centaur in the SPC No. 1 contained six subsystems. These included a strong system for powered flight and a lower power system for coast periods. Camera and data transmission systems were installed to view the liquid hydrogen tank. Ground Support Equipment controlled and monitored the Centaur. [301]

Extensive instrumentation, including 200 transducers and 18 landlines, were used to record the data in the off-site receiving station. The recorded data was edited down at a later date. A number of K-logger chart recording systems were used to record up to 40 different parameters. A television camera, which was controlled and viewed in the SPC control room, was mounted near the lower section of the Centaur. [302]

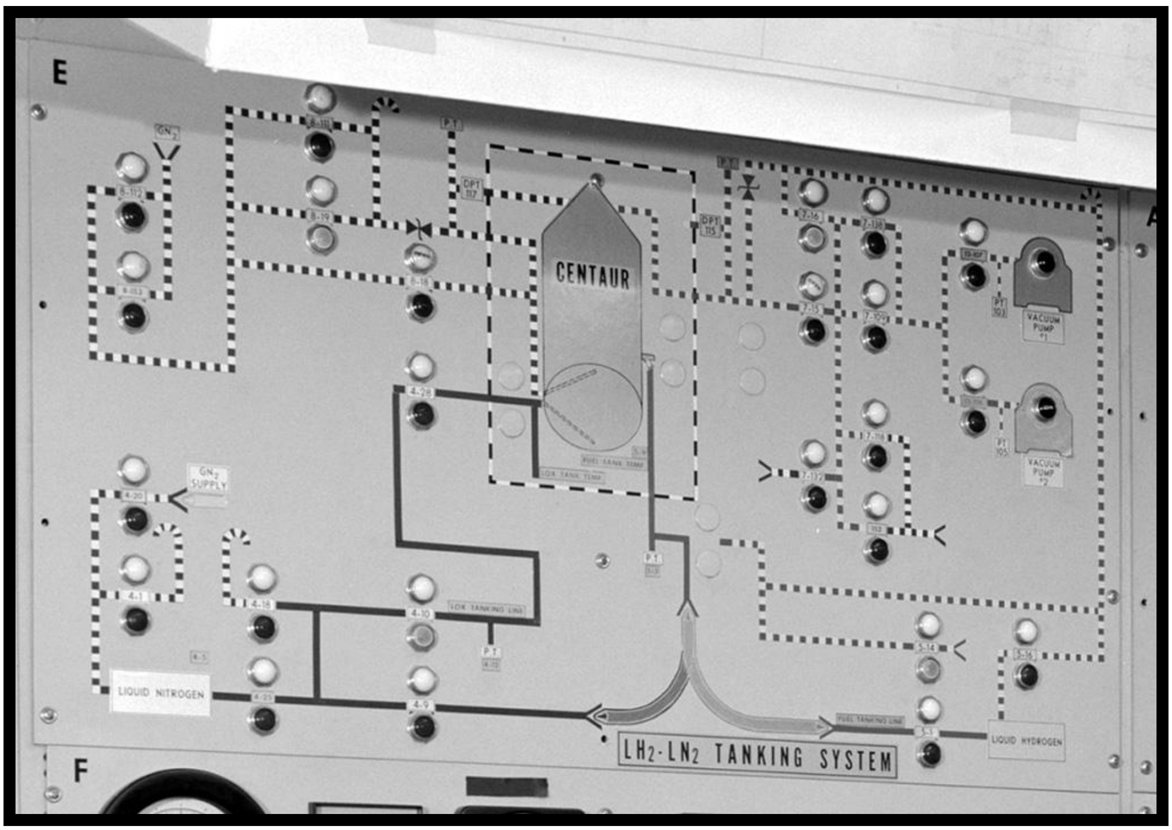
A cable rack ran vertically next to the Centaur inside the chamber and exited the through a portal in the dome. This rack carried the vehicles thermocouple lines and other wiring to the control room below the former wind tunnel test section.[303]



Drawing showing telemetry connections between SPC No. 1 and the control room
SPC Image No.71: CR-151600 01 B/NASA Glenn Research Center

Pneumatic System: The Centaur had thin fuel tanks that required pressurization to retain their proper form. If the pressure difference between the upper section of the vehicle and the lower portion with the fuel tanks changed, the vehicle would likely collapse. A pneumatic system was installed in the SPC No. 1 to maintain this pressure differential at all times. The oxidant pressure was maintained at 8-10 pounds per square inch above the internal fuel tank pressure, which was kept at 4-6 pounds per square inch higher than the chamber pressure.[304]

Hydraulic System: The Centaur's RL-10 engines were hydraulically rotated as they would be during a flight but not fired for the SPC tests. Their boost pump rotors were secured and the propellant lines sealed.[305] All fluid and air lines were hooked up to quick disconnects and all the vents and valves were ducted outside of the chamber. Redundant, parallel electric systems were installed to ensure continuity during the tests.[306]



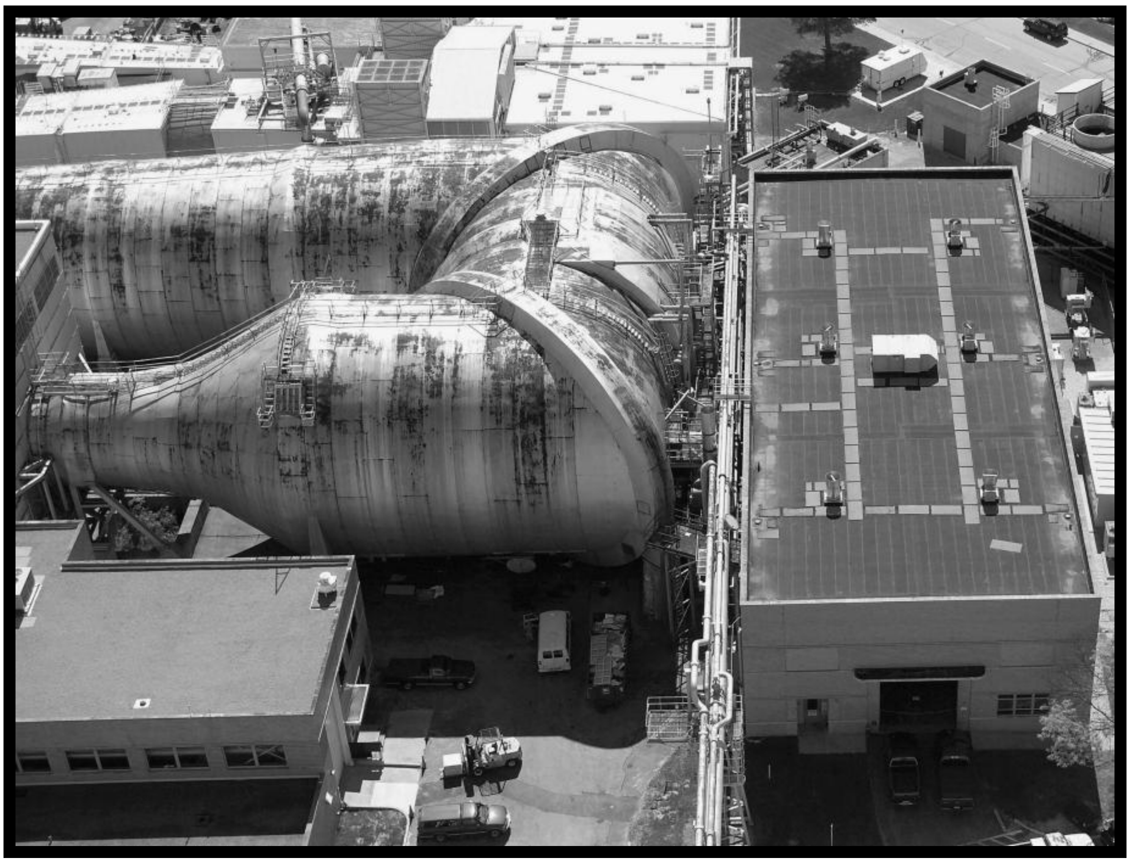
Control panel in SPC control room for the liquid hydrogen / liquid nitrogen tanking system
SPC Image No.72: 1964-68589/NASA Glenn Research Center *(1964)*

Liquid Hydrogen Supply: The Centaur used liquid oxygen as an oxidizer and liquid hydrogen as a propellant. Since the Centaur's engines were not fired during the SPC No. 1 tests, it was not necessary to use the liquid oxygen. Instead liquid nitrogen was oxidizer tank was filled with liquid nitrogen. Because of its density compared to hydrogen, the tank was only filled 10 percent with the nitrogen.[307]

The liquid hydrogen was supplied to the SPC No. 1 through a pumping system that penetrated the lower south wall of the chamber. A large liquid hydrogen dewar was stored on railroad ties beneath the chamber and additional dewars could be added using trucks.[308]

B. Space Power Chamber No. 2

Not including the area used for SPC No. 1 or the former tunnel test section, the remainder of the tunnel was converted into a larger, but less powerful vacuum chamber.[24] This J-shaped chamber ran from the southeast corner, through the south leg, through the west leg, through the throat section, and stopped just to the west of the test section. The longer section in the south leg was approximately 33 feet diameter at its east end and 51 feet diameter at the west. The throat section in the north leg narrowed from 51 feet diameter at the west to 20 feet diameter to the east. The widest section was the 121 foot long, 51 foot diameter west leg. [309]



Aerial view from north of SPC No. 2 exterior
SPC Image No.73: 2007-02581/NASA Glenn Research Center (2005)

[24] For additional information on the chamber's size and structure, see the Altitude Wind Tunnel section of this report.

Shell: The shell for SPC No. 2 was the original wind tunnel shell built in the 1940s.[25] A 1 inch thick chromium and copper-based steel alloy was used to endure the low temperatures of the high altitudes environment. It was covered with fiberglass insulation and a second, thinner steel shell to protect against the weather.[310]

The coating of the facility with a protective grey paint appears to have ceased in the mid-1990s. Rust began to appear on the exterior of the tunnel by 1999 and was extensive by 2005. The outer shell of the tunnel on the roof bowed under human weight.

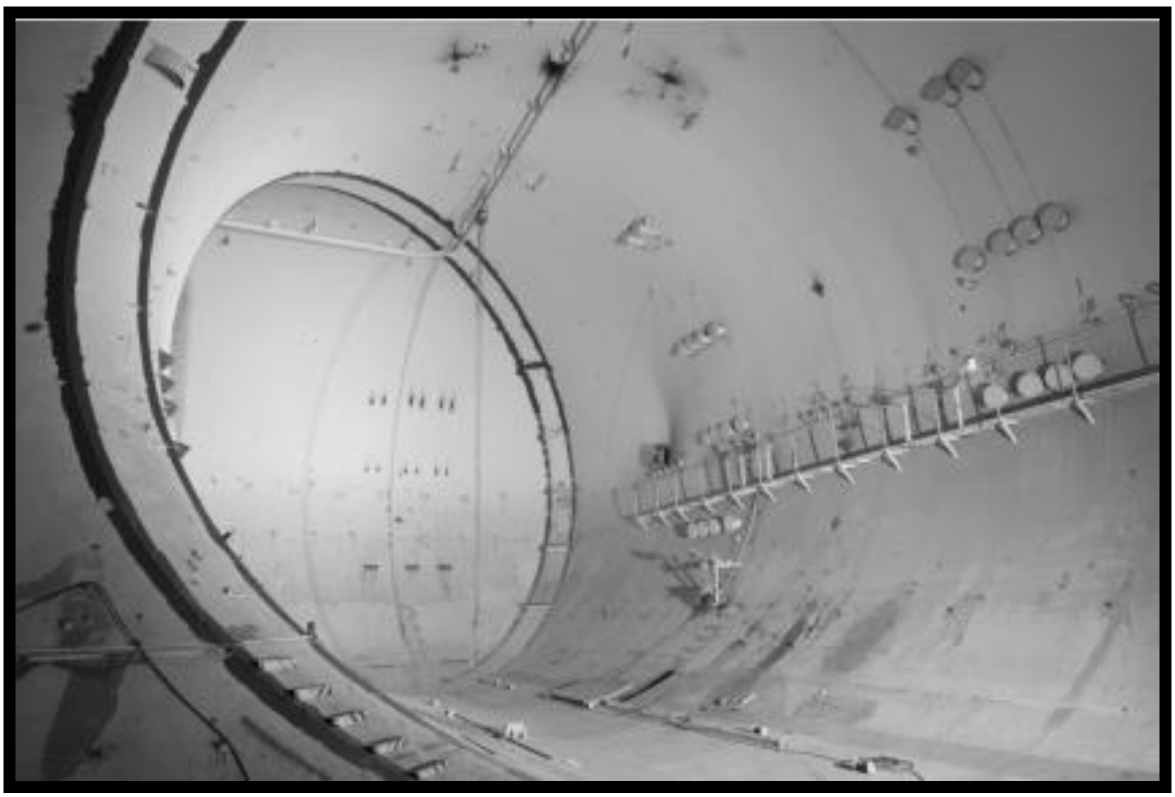
View from south of south leg of SPC No. 2 with walkway on top
SPC Image No.74: 2005-01486/NASA Glenn Research Center *(2005)*

Roof: The roof did have a series of stairs, ladders, and platforms that allowed access. These had steel handrails approximately 3 feet high with a second horizontal bar segmenting it. These were installed in the 1940s. [311]

[25] For additional information see the Altitude Wind Tunnel portion of this report

Interior Walls: Although sections of the area that would be SPC No. 2 were cleaned and repainted a few years prior for the Project Mercury tests, the area was cleaned and repainted again during the conversion to the SPC. The corner rings were flat surfaces which smoothed relatively flush with the walls. These were 42 inches across at their midpoints and widening to 48 inches at the floor. The walls were smooth put did contain a number of obtrusions, particularly in the large western leg where the majority of the SPC No. 2 tests took place. There was a 15-inch by 74-inch rectangular hole cut in later years into the lower western wall.

This 51-foot diameter western leg had a number of former cooling lines and two large make-up air lines that were capped on its western wall in 1958-59.[26] This area also had many fittings and modifications due to the tests performed in SPC No. 2 and for the Project Mercury tests.



View from north of 51 foot diameter western leg of SPC No. 2 with catwalk along outer wall
SPC Image No. 75: 2007-00378/NASA Glenn Research Center (2007)

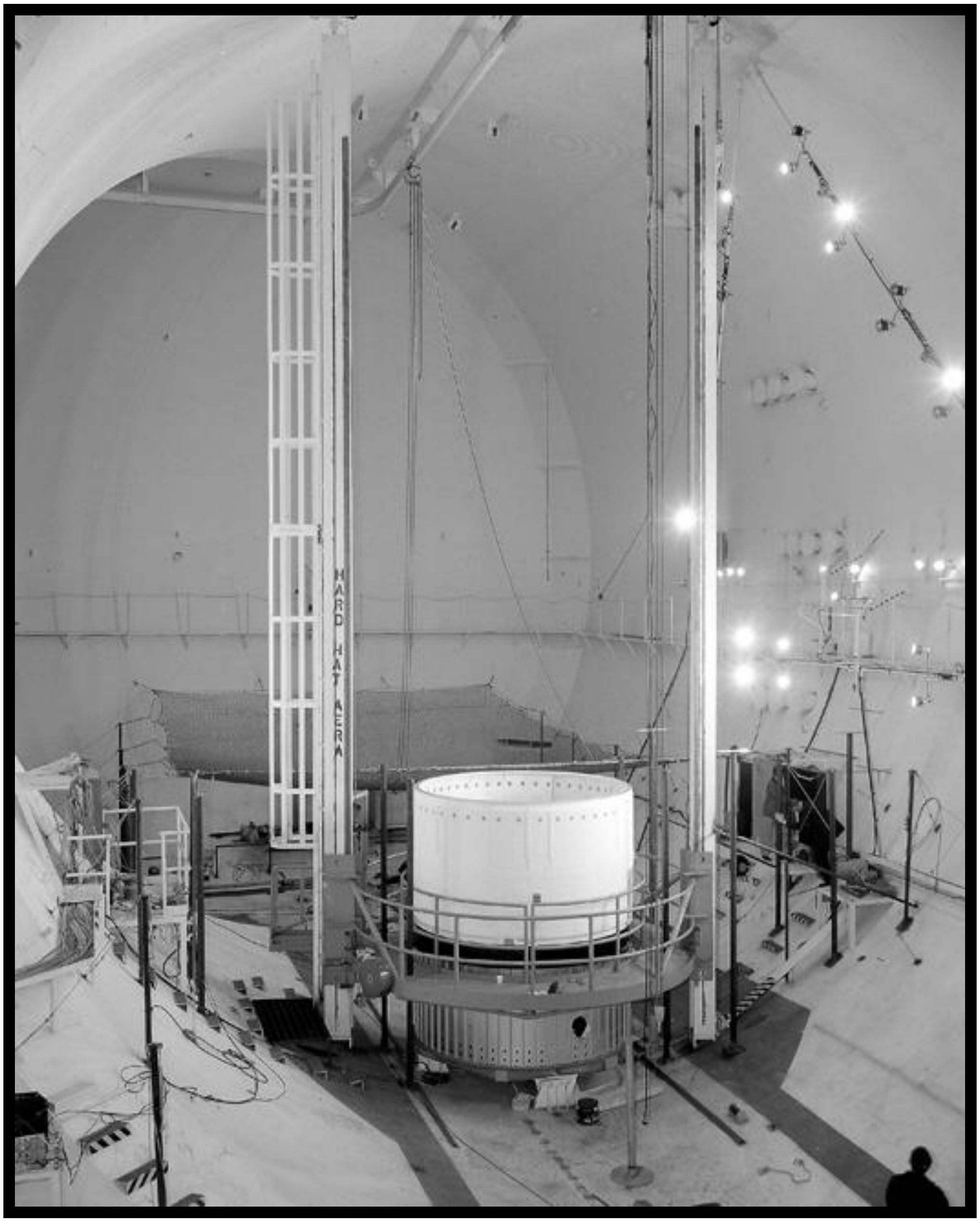
A metal work platform with handrails was mounted to the lower interior wall. Another platform with the handrails was mounted to the center of the exterior wall. These work areas would be added or removed depending on the test being conducted. Several small "toe stairs" were created in the tunnel wall leading up to the platform areas remained however. Other sets of this type of stairs were added on the interior northwest corner ring and on the exterior western wall leading up to longer elevated catwalk along the wall.

This steel grated catwalk ran virtually the entire length of the section at the chamber's approximate vertical midpoint. Banks of floodlights were installed on the wall over the catwalk.

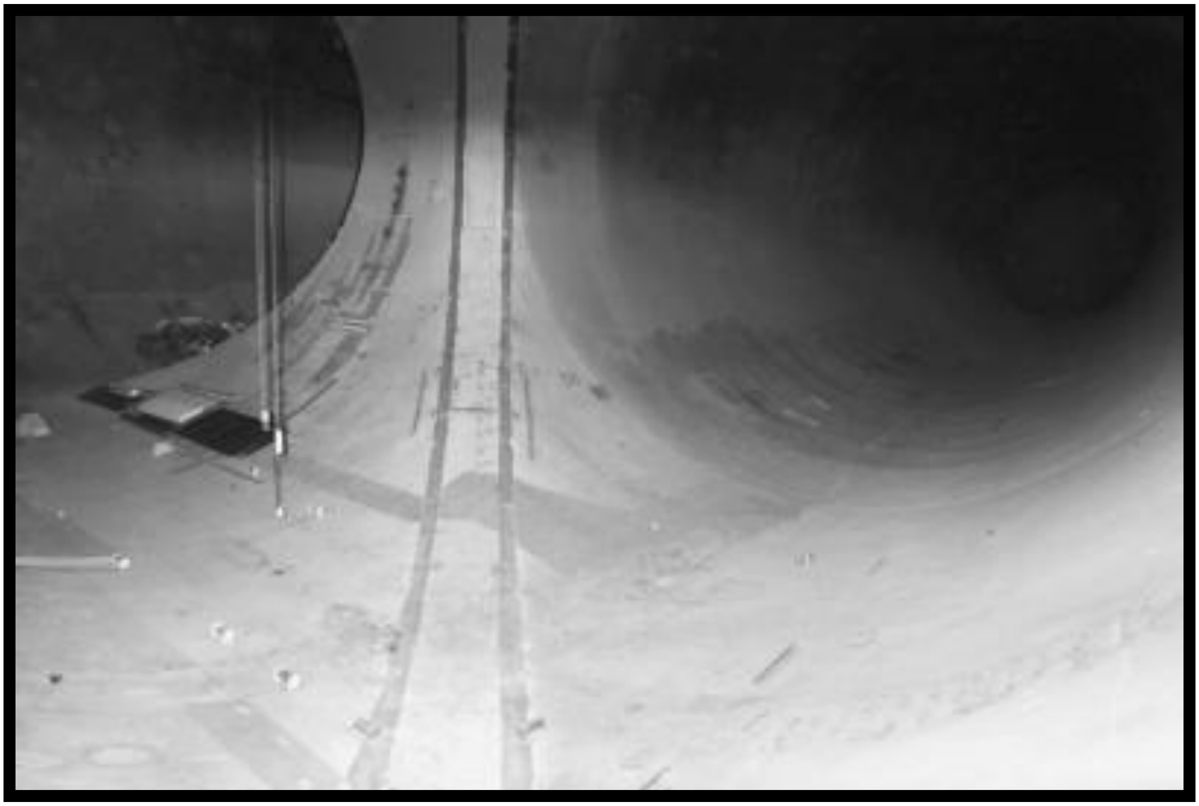
[26] Further description of these items can be found in the Altitude Wind Tunnel section of this report.

Access was provided near the northwest corner by the set of seven toe steps which lade to a small steel platform. From this platform was a fixed ladder leading up to the catwalk.[312]

There were a number of fittings welded to the floor in the western leg. These included four 4-inch diameter cup-like fittings 54 inches apart from one another arranged in a square pattern in the center of the area. Fourteen 10-inch long 3.5-inch diameter tubular fittings were welded to the floor. Ten of these ran in a row north and south, one was on the south end, and three more were on the north end. These were used to tighten the nets for the shroud separation tests.



View from south of western leg of SPC No. 2 with crane, elevator stands, and platforms against the walls.
SPC Image No. 76: 1965-00703/NASA Glenn Research Center (1965)



View from southwest corner of corner ring with western leg of SPC No. 2 in foreground
SPC Image No.77: 2005-01614/NASA Glenn Research Center (2005)

Large test articles were brought through a removable bulkhead at the junction of the tunnel's throat section and test section. A new "squirrel hole" access portal was created in the northern leg near the northwest corner of the tunnel in early 1959 to allow personnel into the chamber for the Multi Axis Space Test Inertia Facility tests. In recent years this would provide the only entrance into the chamber.

This "squirrel hole" entrance was a 8-foot 8-inch long, 48-inch diameter tube that ramped from the exterior of the tunnel into the wide section. The interior opening was 58 inches wide and 82 inches in diameter with a slight concrete collar around it. The exterior opening had a steel lip with bolt holes around it. The tube had a hand rail and floor steel treads. A short set of metal stairs provided access to this entrance from the exterior.[313]

Interior view of squirrel hole entrance into SPC No. 2
SPC Image No. 78: 2005-01622/NASA Glenn Research Center (2005)

Views of interior and exterior of access door built into north wall of SPC No. 2
SPC Image No. 79: 2005-01632/NASA Glenn Research Center (2005)

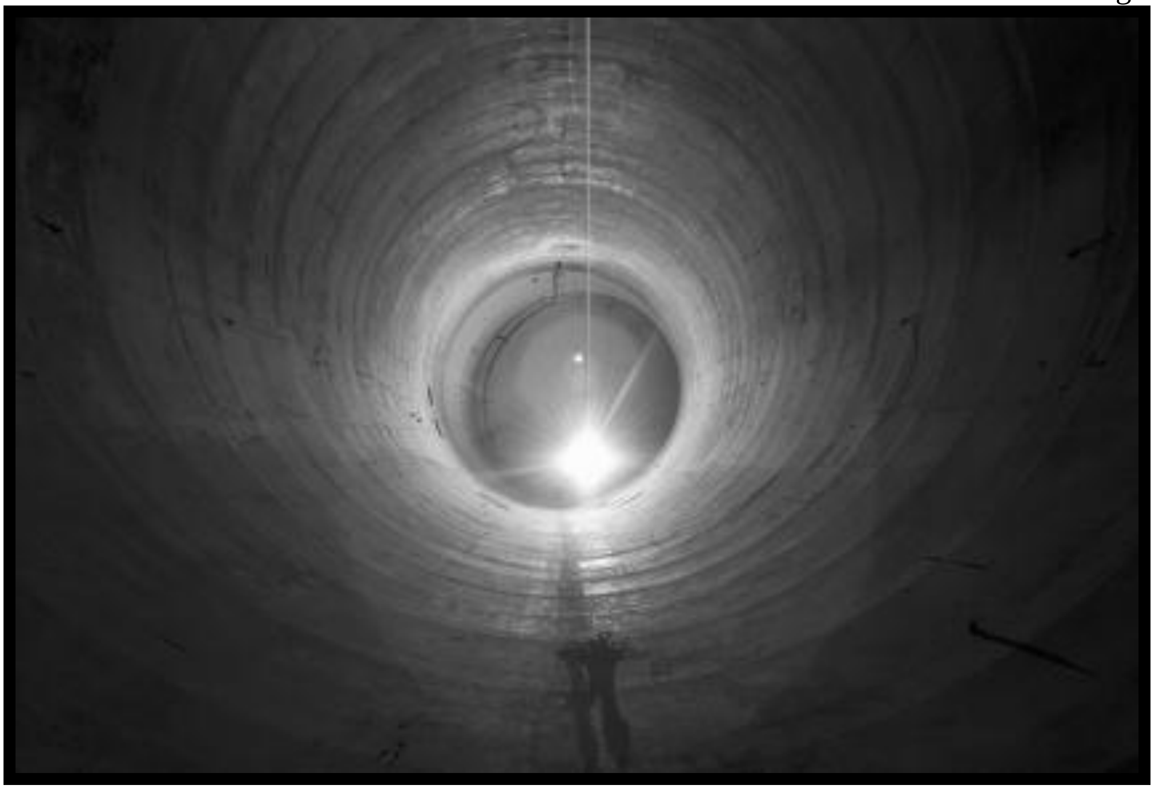
View west from throat section of SPC No. 2 showing overhead crane and catwalk
SPC Image No. 80: 1963-65546/NASA Glenn Research Center *(1963)*

The former tunnel throat section, which narrowed the tunnel's diameter from 51 feet to the 20 feet, had a 20-step metal stairway from the chamber floor to a platform level with the test section. An Industrial PAX telephone was mounted on a 35.5-inch pole at the base of these steps for the MASTIF tests. A small metal platform was mounted to the inner wall at the top of the stairs.

A 16-step stairway led to a small platform along the northern wall. A steel ladder rose from this platform to a catwalk that ran overhead through the western leg for the Project Mercury tests. This catwalk was shortened during the creation SPC No. 2. The interior wall of the throat section had several steel grated platforms mounted to the curved walls.[314] These were installed or removed depending on the test being conducted. The northern steps, catwalk, and platforms were permanently removed years ago.

View east of the throat section of SPC No. 2 with bulkhead at far end
SPC Image No.81: 2007-00372/NASA Glenn Research Center (2007)

View east of the throat section of SPC No. 2 with steps and telephone in foreground
SPC Image No. 82: 2007-00390/NASA Glenn Research Center (2007)

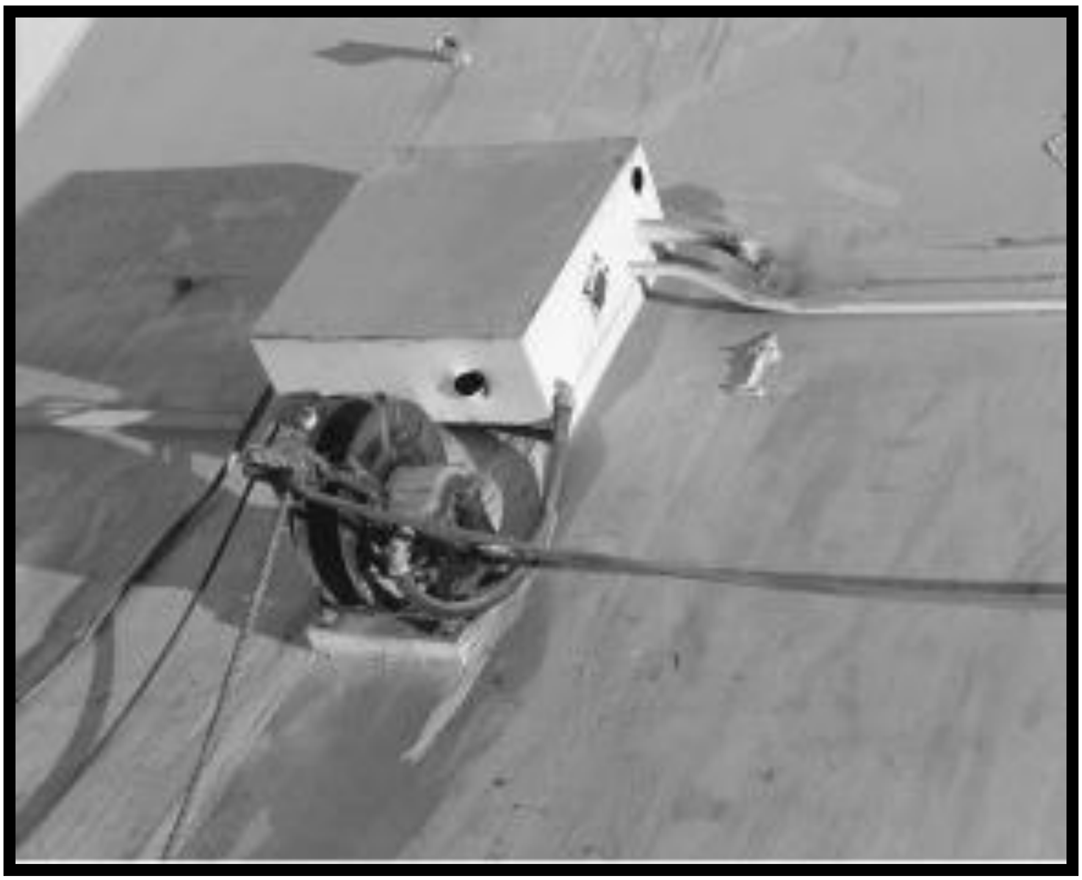


View from east of south leg of SPC No. 2
SPC Image No. 83: 2007-00383/NASA Glenn Research Center *(2007)*

View from west of south leg of SPC No. 2
SPC Image No. 84: 2007-00380/NASA Glenn Research Center *(2007)*

The interior of the south leg of SPC No. 2 had few obtrusions except several eyehooks welded to the lower walls near the west corner. In recent years several rectangular several square holes were cut into the lower half of the tunnel walls which reveal the insulation, mesh, and outer shell. There were two T-bars set up near the bulkhead in the southeast corner with the cross bar being approximately 36 inches high.

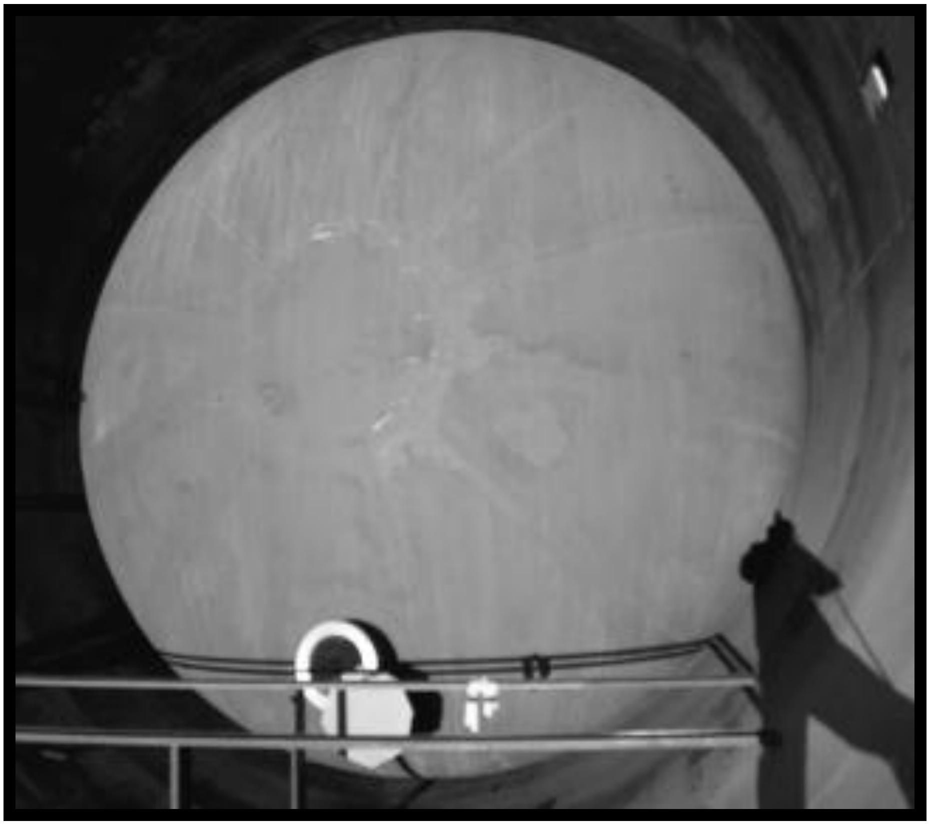
In 2007, the overall condition of the interior of the chamber was fairly good considering it had not been maintained in over thirty years. The walls did have some rusting, particularly near the southeast corner and along the seams. The welds at the support ring seems were numbered with spray paint in recent years.



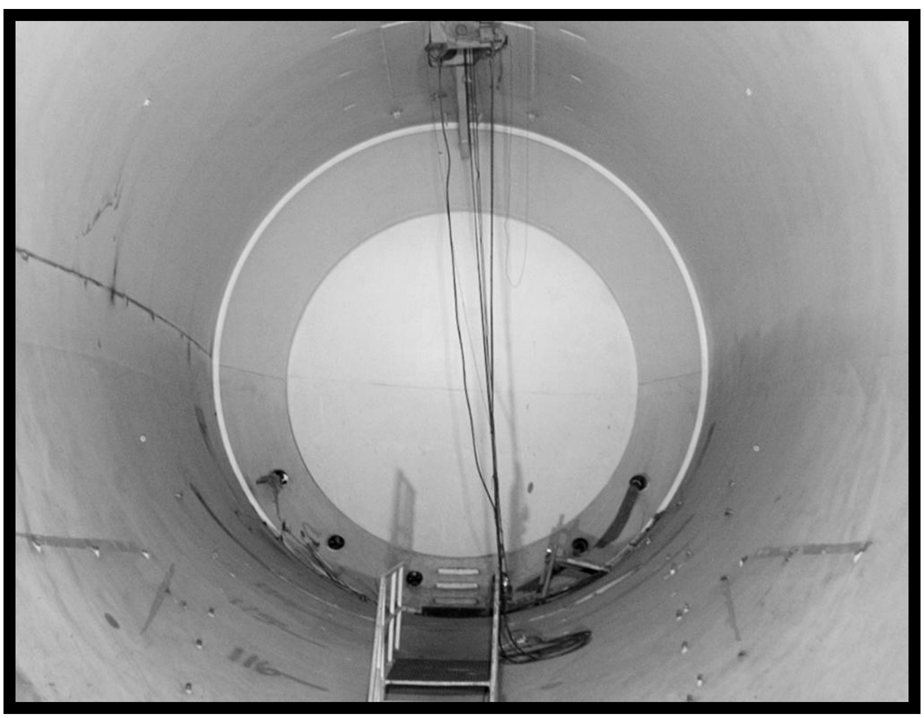
Hoist box installed on inner wall just prior to throat section
SPC Image No.85: 2007-00376/NASA Glenn Research Center *(2007)*

Bulkheads: SPC No. 2 was sealed off from SPC No. 1 by a 31-foot bulkhead near the southeast corner. This bulkhead was painted red on the SPC No. 2 side and bowed into the chamber. It contained a 24-inch diameter viewing port approximately 24 inch from the chamber floor to look into SPC No. 1.[315]

SPC No. 2 was sealed off on it the other end by a 20-foot diameter bulkhead between the throat section and the former wind tunnel test section. This concave bulkhead had an approximately 3-foot deep lip around it that expanded into the throat section and a flat 20-foot diameter plate.



View east from SPC No. 2 of 31 foot diameter bulkhead near southeast corner
SPC Image No. 86: 2007-00382/NASA Glenn Research Center (2007)

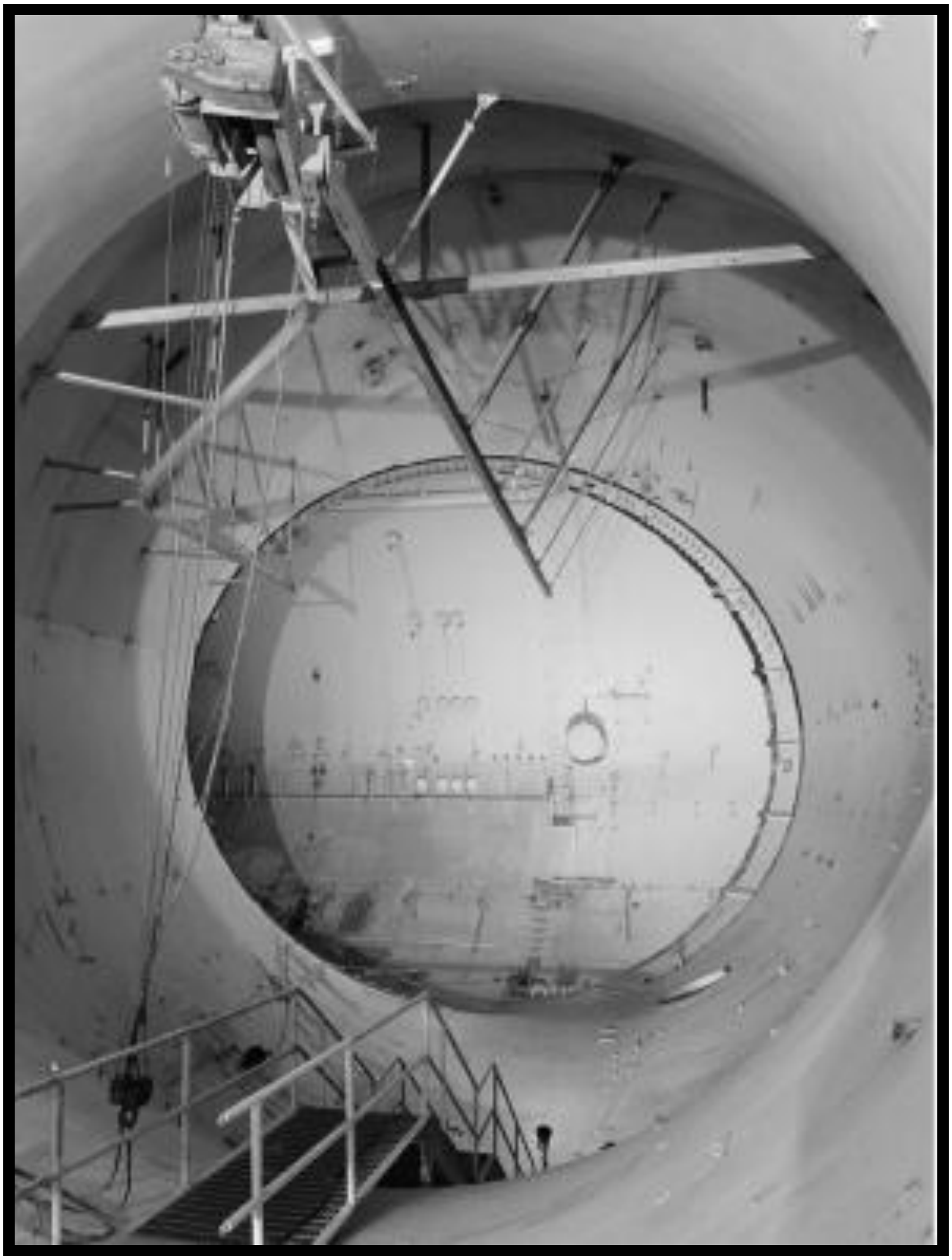


View east from SPC No. 2 of 20 foot diameter bulkhead near west end of former test section
SPC Image No. 87: 2007-00374/NASA Glenn Research Center (2007)

Elevator: SPC No. 2 included an oval platform elevator on vertical steel girders that could be raised the entire height of the chamber. The elevator's 11-foot interior diameter allowed the structure to be placed around payload shrouds to assist in separation test preparations. [316] The steel girders were mounted to the chamber floor and secured to the roof. Pulleys at the top of the shafts were attached to weights at the bottom. Cameras were set up on top of each post to film the separations, and a metal enclosed ladder ran the length of the southern post.[317]

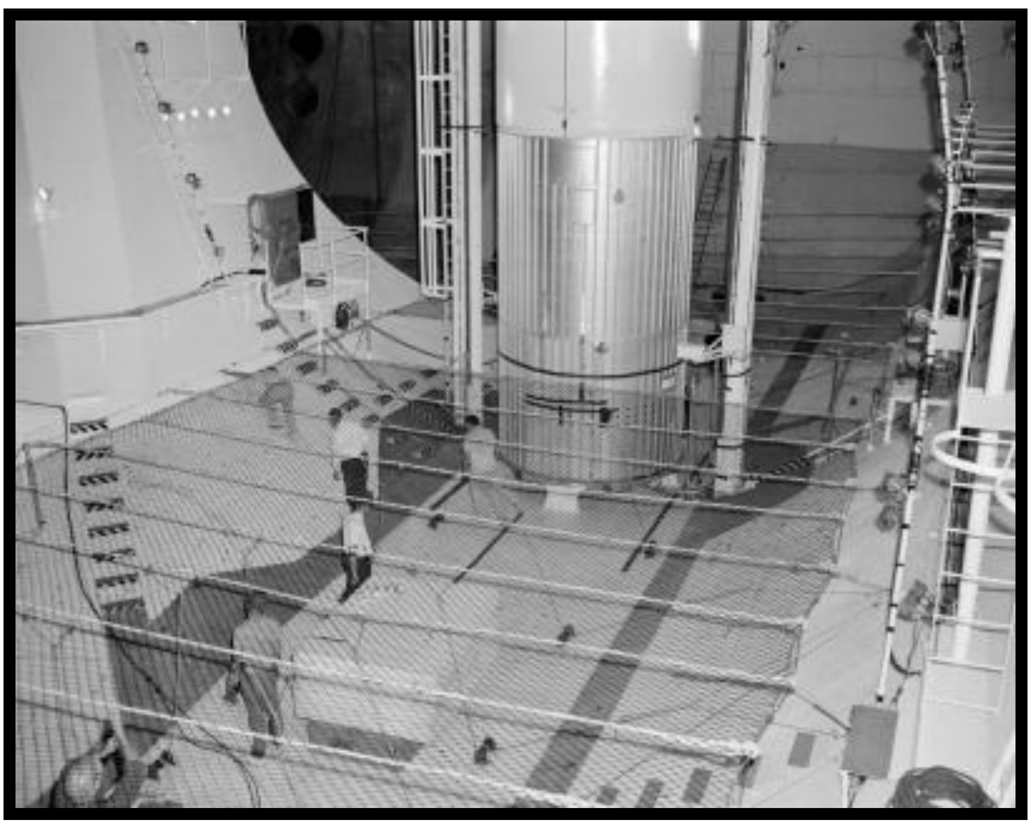
View from north of platform elevator in SPC No. 2 lifted above Centaur model
SPC Image No. 88: 1968-00499/NASA Glenn Research Center (1968)

Cranes: SPC No. 2 had two overhead monorail cranes. The first was a westward sloping crane installed in the throat section for the Project Mercury tests. It was suspended from the chamber ceiling by six pairs of struts and a cross beam. Within the throat section this crane had a second track that veered to the south providing access to areas near the inner wall. The second crane was ran along the SPC No. 2 ceiling the length of the western leg then curved and traveled several feet into the south leg. This crane had a handheld control box that hung from the track.

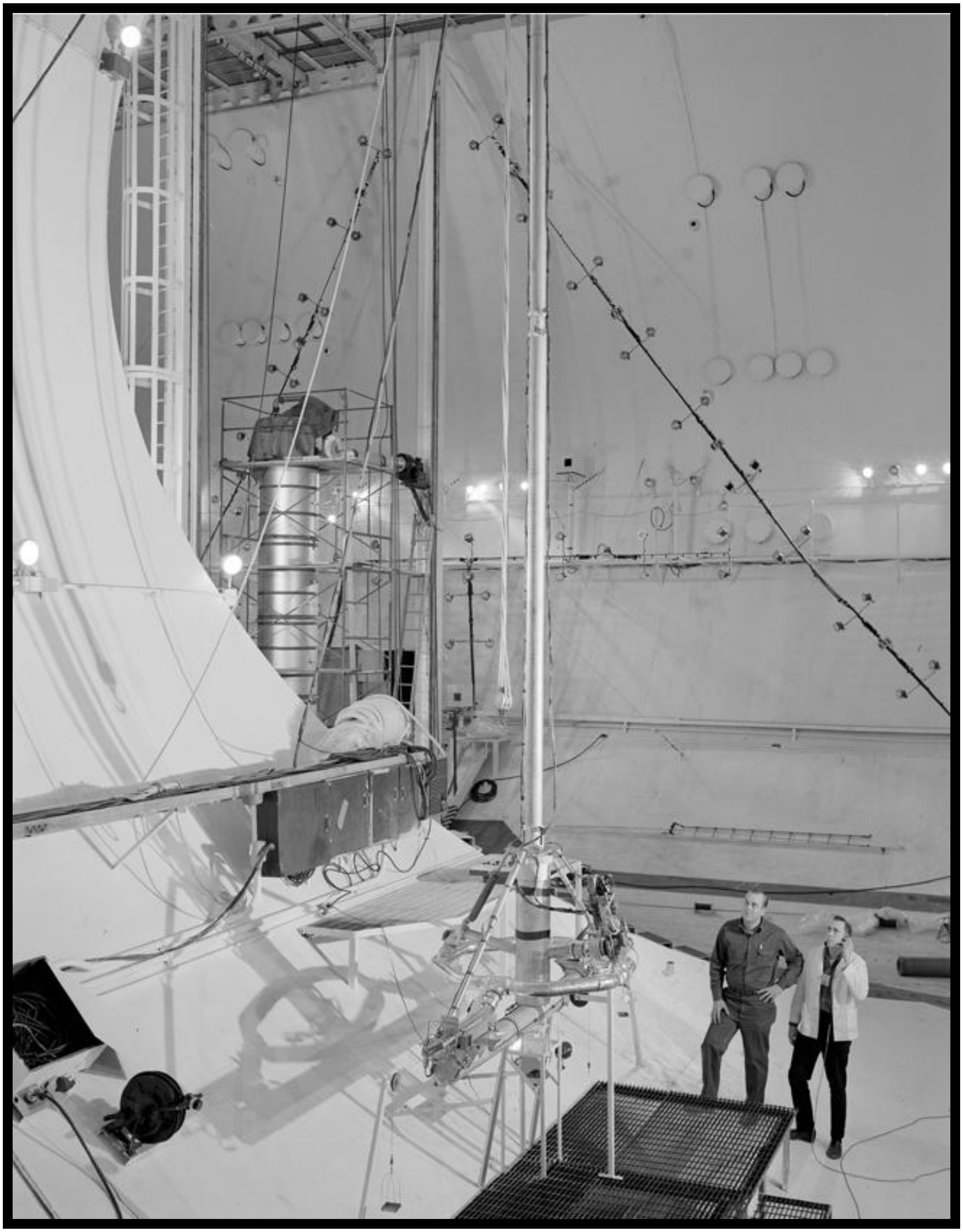


View westward from throat section showing overhead crane with its two rails
SPC Image No. 89: 2007-00396/NASA Glenn Research Center (2007)

View up at crane in western leg of SPC No. 2 near southwest corner
SPC Image No. 90: 2005-01611/NASA Glenn Research Center (2005)



View of tie downs and net strung across SPC No. 2 to catch shroud during separation test
SPC Image No. 91: 1965-01670/NASA Glenn Research Center (1965)



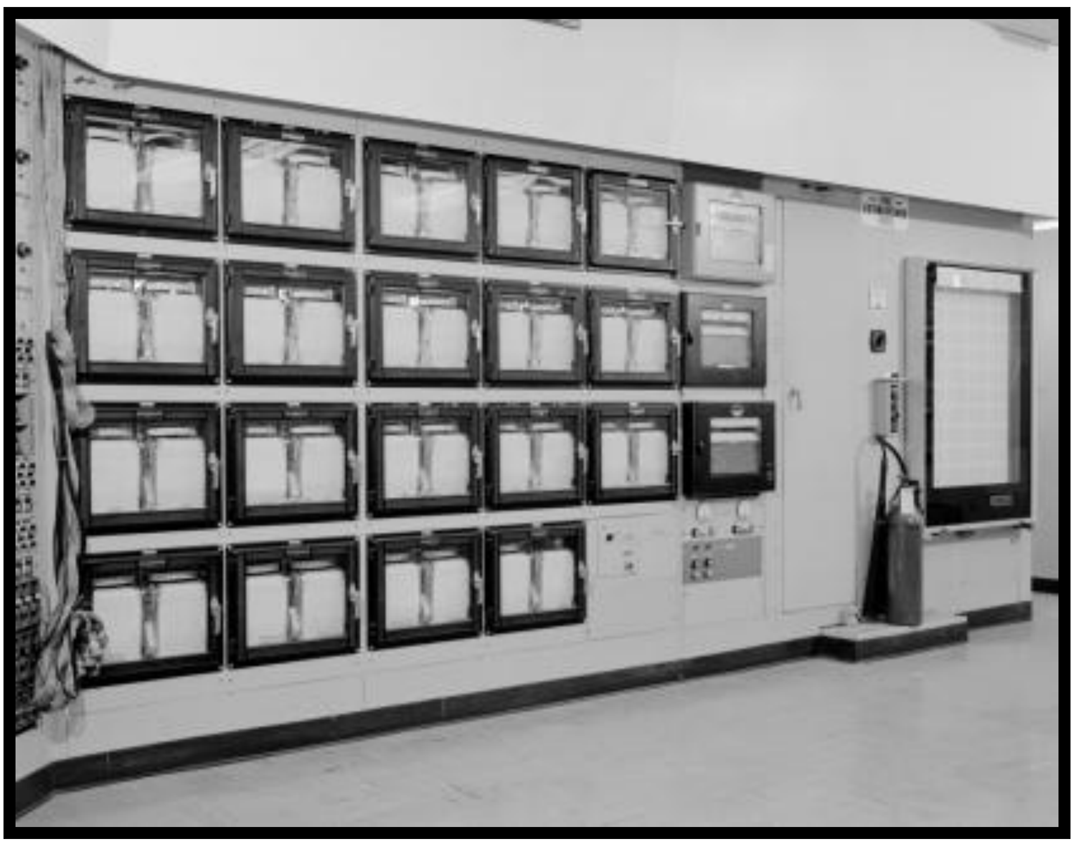
View of equipment mounted to interior wall near throat section
SPC Image No. 92 1965-03509/ NASA Glenn Research Center *(1965)*

E. Space Power Chamber Building:

The former Shop and Office Building, renamed the Space Power Chamber (SPC) Building in 1963, contained offices, high-bay, shop area, two control rooms, and other support for the work being conducted in the SPC.[27] The building was originally constructed in the 1940s to support the wind tunnel, but many of its functions were transferred to the SPC in the early 1960s.

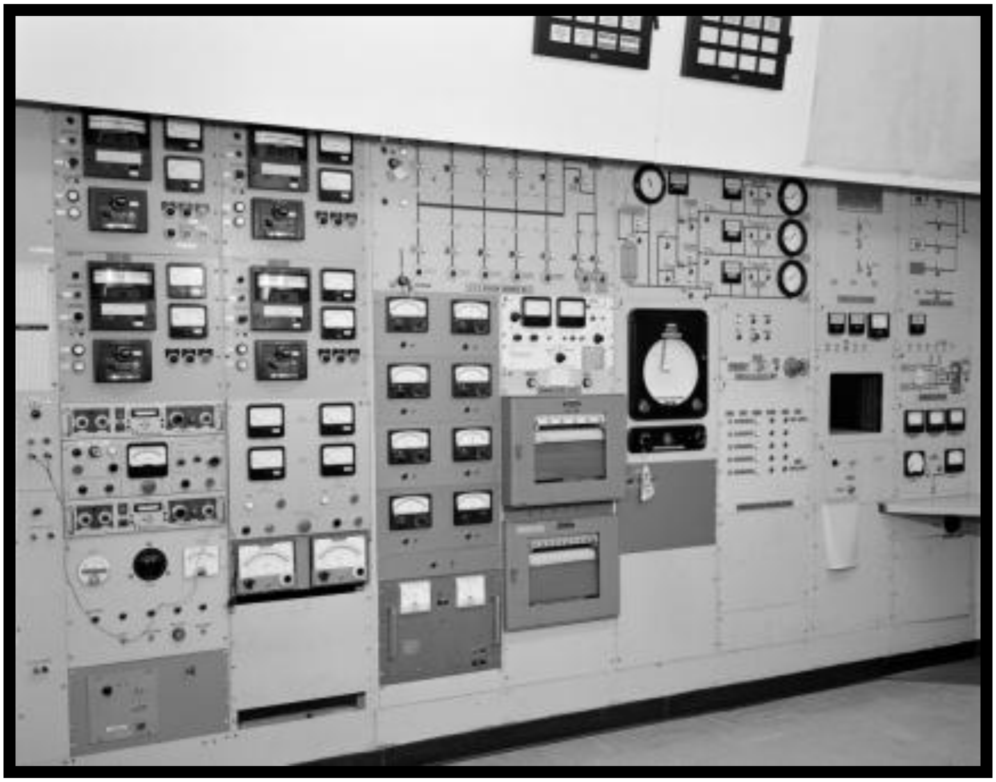
SPC No. 1 Control Room: A new control room to operate SPC No. 1 was constructed in the balance chamber underneath the former tunnel test section. Efforts were made to make this control room as much like the Centaur launch controls at Cape Canaveral as possible.[318] The 23-foot 7.25-inch wide and 20-foot 11.75-inch long room went through the bulkhead that separated the tunnel's balance chamber from the rest of the building.[319] Access was provided through the mezzanine level of the SPC Building.

The arrangements of the control panels made the room's interior appear octagonal. The eastern section had the vehicle pressure and tanking controls; hydrogen peroxide, hydraulic, stretch, pneumatic, and canister purge systems; the baffle and vacuum systems, and solar simulator temperature monitor. The northern section consisted of temperature and pressure monitors, electrical power controls and monitor, signal conditioning, and a solar simulator temperature monitor.

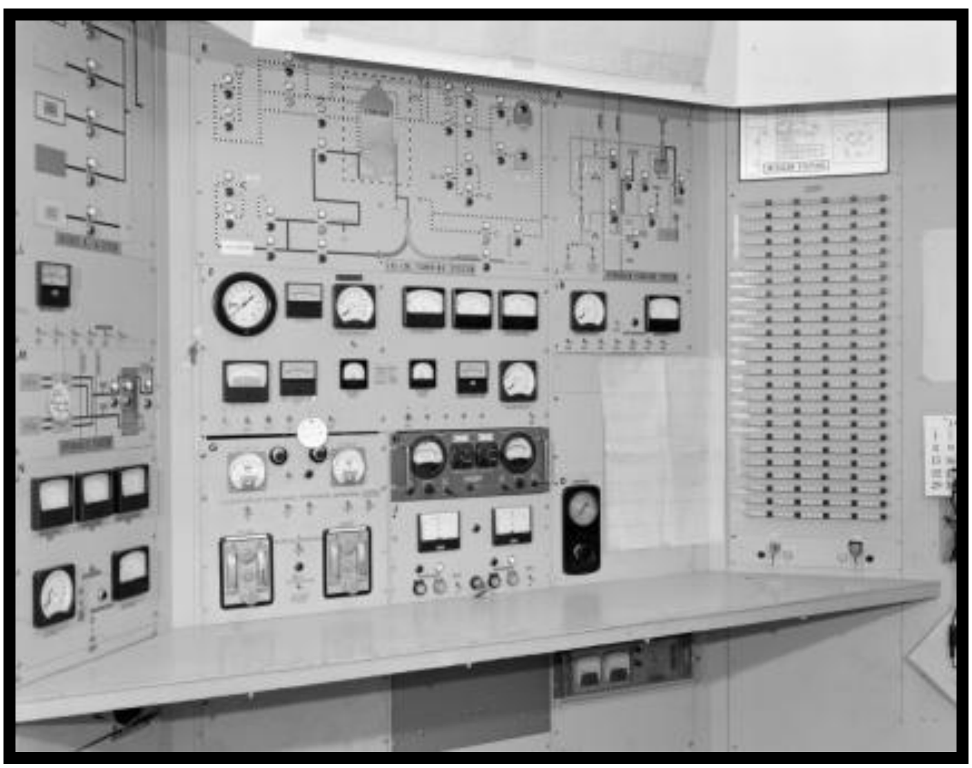


View of southern wall in SPC No. 1 control room with various event monitors
SPC Image No. 93: 1967-00189/NASA Glenn Research Center *(1967)*

[27] For description of the Shop and Office Building and its renovations see the Support Buildings portion of this document.



View of control panels on east wall of SPC No. 1 control room
SPC Image No.94: 1967-00183/NASA Glenn Research Center (1967)



View of Centaur tanking system panels in southeast corner of SPC No. 1 control room
SPC Image No. 95: 1967-00193/NASA Glenn Research Center (1967)

The western wall contained the guidance system, C band system, azusa system, nose cone, and vent valve monitors. The southern section had data and event recorders, RF and range safety monitors.

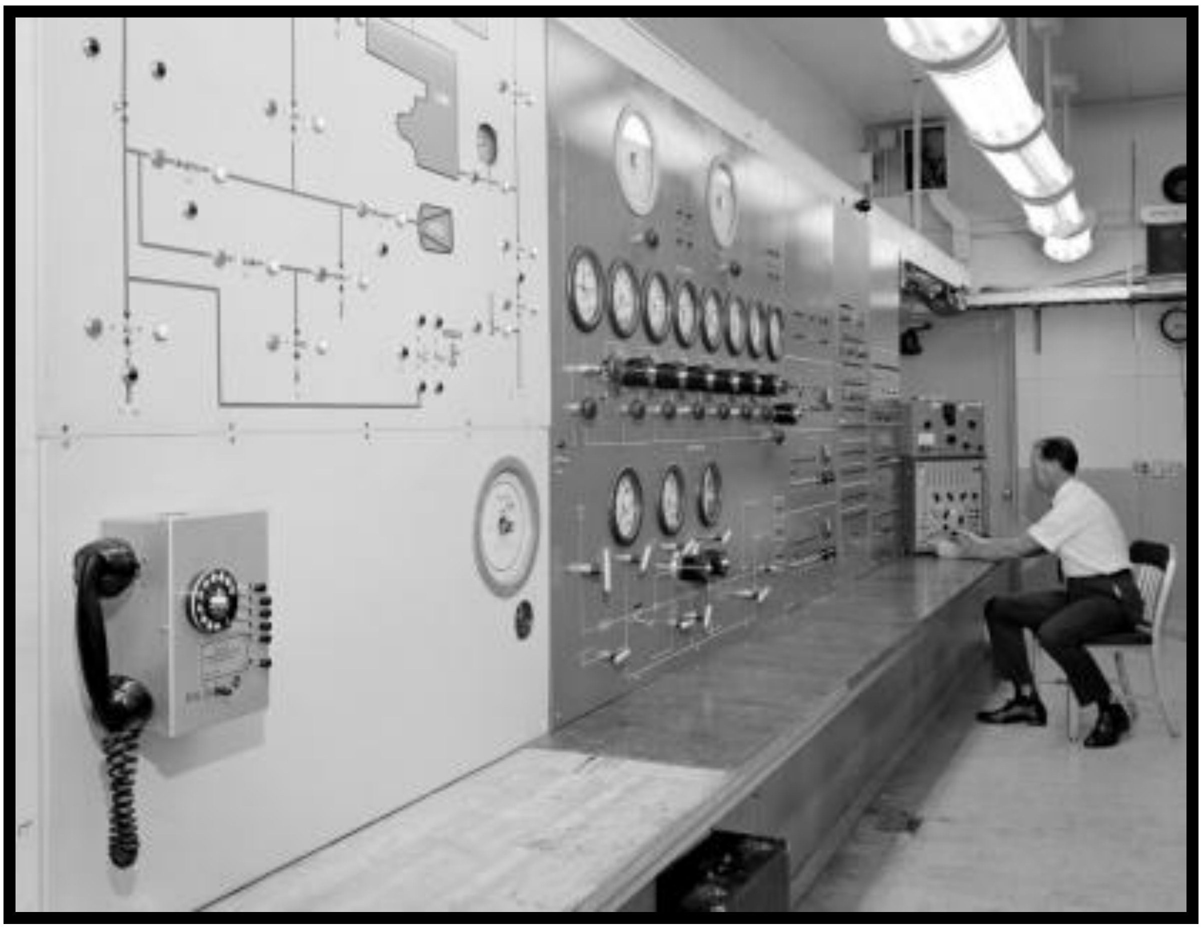
The center of the room had two racks of control panels running parallel north and south. The eastern rack contained the test conductor controls, ground programmer, vehicle power monitor and flight control, and engine controls. The western rack contained data recorders manufactured by Brush Instruments. The exterior of the octagonal set-up was a walkway with minor pieces of equipment such as telephones, air conditioners, and gas detectors.[320]

View of data recorders in western rack in center of SPC No. 1 control room
SPC Image No. 96: 1967-00188/NASA Glenn Research Center *(1967)*

The original air lock into test section on second floor was removed in 1995.[321] At this time, this section of the building went under a major rehab. The stairs were bolstered, walls repainted, a suspended acoustical ceiling installed, and office areas modernized. The SPC No. 1 control room was remodeled and used as the Far Field Antenna lab.[322] The control room area is now used as a small laboratory for antenna testing. It was not effected by the demolition of the tunnel in 2009.

SPC No. 2 Control Room: The former wind tunnel control room was converted into the control room for the tests in the SPC No. 2 altitude chamber. This primarily involved rewiring the telemetry and updating the control panels. The tunnel's floor-mounted pneumatic engine controls were removed. The panels ran east and west along the south wall of the room. The original acoustic tiles on the walls and ceiling remained, as did the overhead fluorescent light fixtures.

The eastern panel controlled the exhaust flow from SPC No. 2, SPC No. 1, the Propulsion Systems Laboratory, Engine Research Building, and the cooler. These areas were laid out schematically on the panel with toggle switches and indicator lights. The next panel operated the liquid nitrogen system. It consisted of thirteen clock faced dials and many tank pressurization controls. The panel at the west end contained a large number of controls for cameras inside SPC No. 2.



View from east of SPC No. 2 control room with air flow control panel in foreground
SPC Image No. 97: 1963-66247/NASA Glenn Research Center *(1963)*

View facing west of interior of SPC No. 2 control room with control panel on left
SPC Image No. 98: 1963-66373/NASA Glenn Research Center (1963)

View from west of SPC No. 2 control room
SPC Image No. 99: 1963-66246/NASA Glenn Research Center (1963)

Index of Space Power Chamber Photographs

SUPPORT BUILDINGS
(Altitude Wind Tunnel – Microwave System Lab)
NASA Glenn Research Center at Lewis Field
Cleveland
Cuyahoga County
Ohio

Architectural Information: Support Buildings

WRITTEN HISTORICAL AND DESCRIPTIVE DATA
PHOTOGRAPHS

Bob Arrighi
Wyle Information Systems, Inc.
NASA Glenn History Office

January 2009

Support Buildings Section Contents

ALTITUDE WIND TUNNEL
Support Buildings

Location: National Aeronautics and Space Administration (NASA)
John H. Glenn Research Center at Lewis Field
21000 Brookpark Road
Cuyahoga County, Ohio

The facility is located in the wedge-shaped block of Ames, Moffett, Durand, and Taylor roads near the center of the Glenn Research Center. The facility's T-shaped Shop and Office Building faces north on Ames Road with the tunnel forming a rectangle behind. The other support buildings are in the immediate vicinity.

Elevations: The Shop and Office Building was at 754 feet, Refrigeration Building 754 feet, Exhauster Building 755 feet, Cooling Tower No.1 752 feet, and Air Dryer Building 753 feet.[323]

UTM Coordinates: 17 427938E 4585154N (NAD83)
Latitude: 41.41471, Longitude: -81.86227
Quadrangle: Lakewood, Ohio

Present Owner: NASA John H. Glenn Research Center at Lewis Field

Present Use: The tunnel's primary building, Building 7, is presently named the Microwave Systems Laboratory and contains near-field and far-field antenna testing ranges operated by the Communications Division. The office portion of Building 7 is used primarily as office space by the NASA Glenn Educational Programs Office. Building 7 was not included in the demolition of the tunnel.

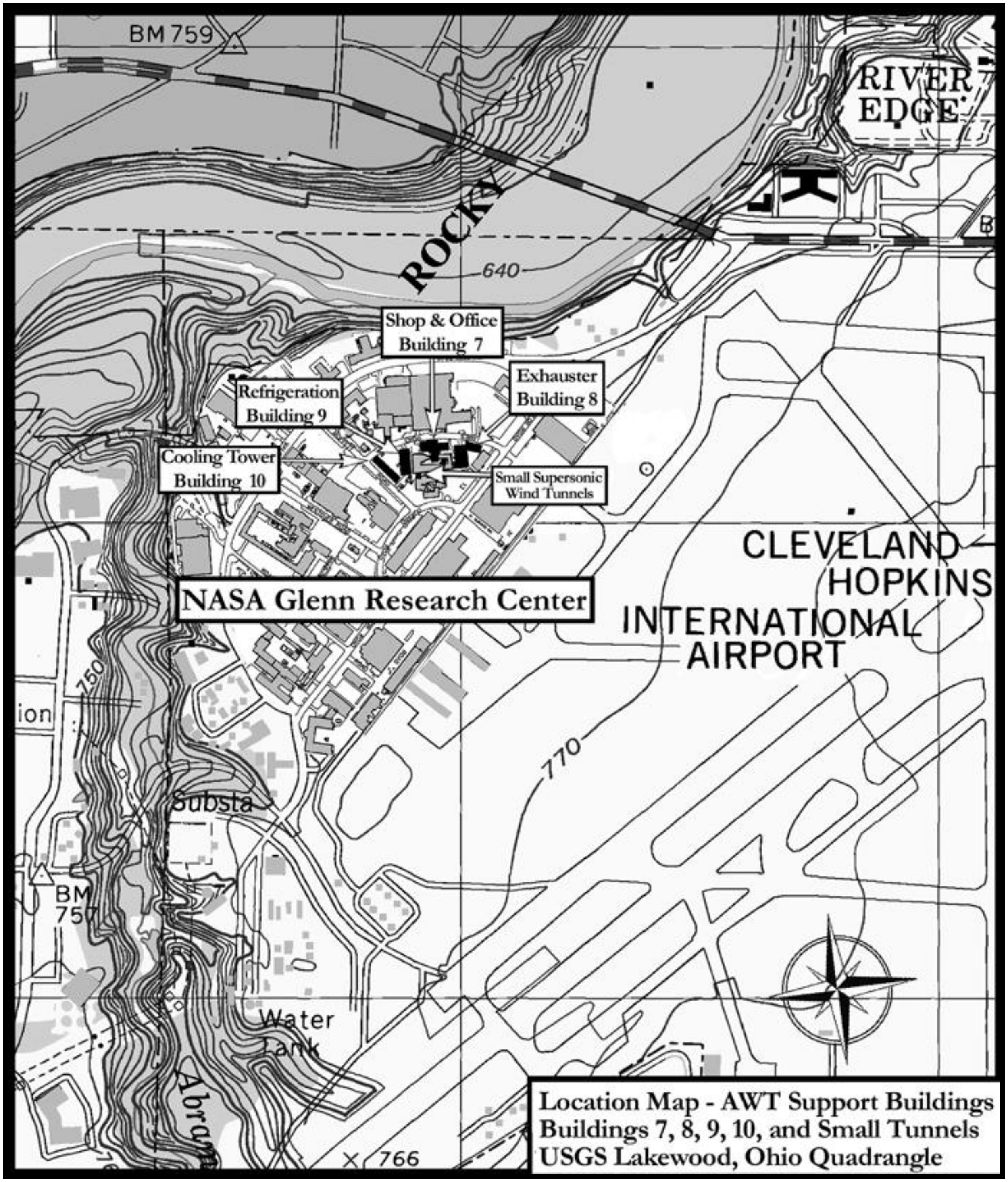
In the 1990s and 2000s, the former wind tunnel test section, also in Building 7, has been used for storage by the Communications Division. Various large pieces of equipment are stored inside the test section, and the surrounding test chamber room is littered with excess equipment and supplies. The chamber's overhead crane remains in working condition and is used by the Microwave Systems Laboratory. The former tunnel control room on the mezzanine level has been gutted, and the space reconfigured as a storage room. The interior of the wind tunnel itself had not been used as a test facility since the mid-1970s. Its interior was used as a storage area until its demolition in 2009.

The Refrigeration Building and Cooling Tower No.1 continue to be used in their originally roles of providing refrigeration for the Icing Research Tunnel. The exhauster equipment was removed from the Exhauster Building in the early 1970s. The building and its annex were converted into the Aerospace Information and Display Building shortly thereafter. The displays were expanded and it was renamed the Visitors' Information Center by the mid-1970s.

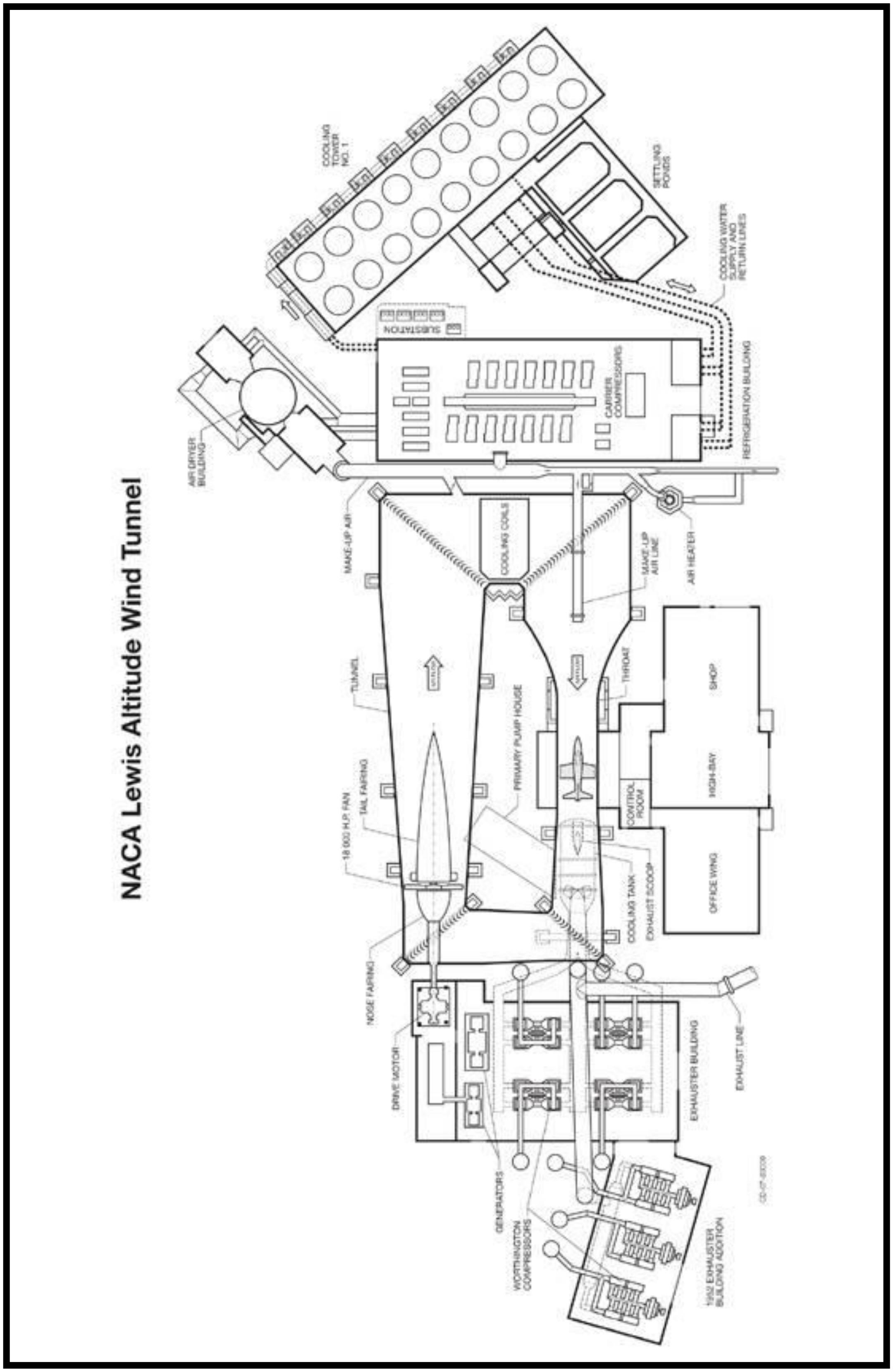
The Circulating Water Pump House (Building 78, renamed the Solar Power Annex) and the Vacuum Pump House created for the Space Power Chambers were used in later years for storage by the Educational Services Division. Both of these structures were demolished with the tunnel.

The Duct Lab, a 4 by-10-inch wind tunnel in the basement of Building 7, remains in working condition. It has been used for development of supersonic injectors, artificial intelligence methods, non-intrusive laser systems, and for flow physics studies and investigations of continuous Mach 1.6 to 5.0, flow physics.[324] The Small Supersonic Wind Tunnels Building was demolished in the early 1980s.

The AWT complex including Shop and Office Bldg.(c), Exhauster Bldg(l)., and Refrigeration Bldg.(r).
Support Image No.1: 2007-02581/NASA Glenn Research Center (2006)



Support Image No. 2: Location Map – AWT Support Buildings



AWT Layout: Diagram showing AWT with its internal components and support buildings.
Support Image No. 3: NASA Glenn Research Center

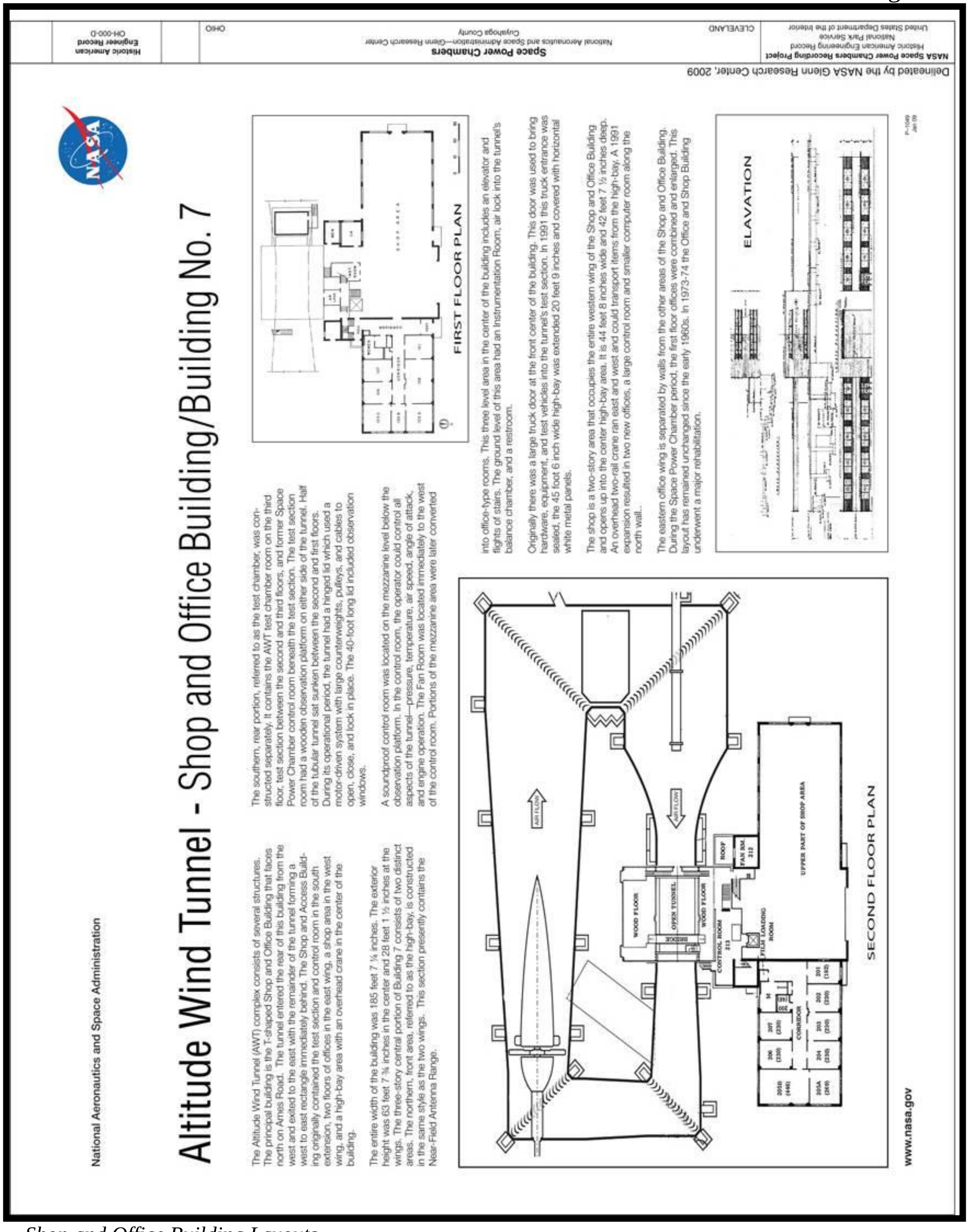
Original Plans: The Altitude Wind Tunnel (AWT) complex consisted of several structures. Building 7 (presently the Microwave Systems Laboratory but historically referred to as the Shop and Office Building) is a T-shaped building into the rear of which the tunnel entered from the west and exited to the east. The remainder of the tunnel formed a rectangle immediately behind. The Shop and Office Building originally contained the test chamber and control room, two floors of offices in the east wing, a shop area in the west wing, and a high-bay area with an overhead crane running north and south down the middle of the building. The test chamber room in the rear was an open two story space with the tunnel sunken in the floor.

The Exhauster Building (Building 8) is a two-story rectangular structure located immediately to the east of the wind tunnel. It contained the compressors and exhausters used to remove air from within the tunnel to recreate the thin atmosphere found at high altitudes. The equipment also removed the hot air exhausted by the engines being tested in the tunnel. The Exhauster Building also contained the drive motors used to spin the large drive fan that created air speeds up to 500 miles per hour inside the tunnel.

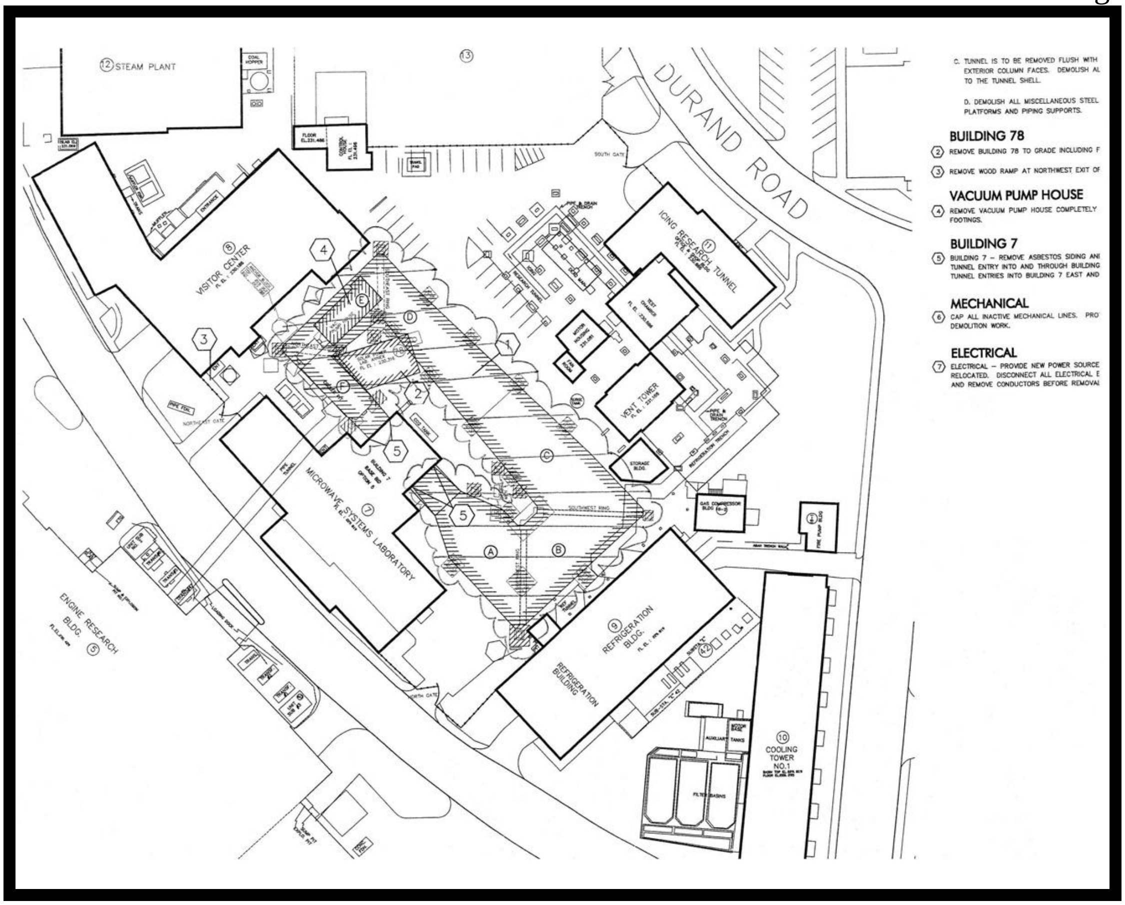
The Refrigeration Building (Building 9) is a rectangular structure located to the immediate west of the tunnel. It contained the compressors and other refrigeration equipment used to create the low temperatures inside the tunnel that corresponded with those found at high altitudes. It also cooled the new air added to the tunnel's air flow, and created chill water for much of the laboratory.

The Air Dryer Building cooled and dried atmospheric air before it was introduced into the tunnel's air stream. Other related buildings include Cooling Tower No.1 (Building 10), the Steam Plant (Building 12), and the electrical Substation B (Building 13). The Vacuum Pump House and the Circulating Water Pump House (Building 78) were located underneath the tunnel. The former housed the vacuum pumps for the Space Power Chamber in the 1960s. The latter supplied an exhaust gas cooler that was used to reduce the temperature of the engine exhaust before it was expelled.

The Small Supersonic Wind Tunnel Building, formerly located just off the southwest corner of the AWT, used the AWT's dry refrigerated air to operate three small supersonic wind tunnels. The Duct Lab in the basement of the Shop and Office Building initially used the tunnel's compressors and later the center's primary exhaust system to operate a 4 by-10-inch supersonic flow physics tunnel.



Shop and Office Building Layouts
Support Image No. 4: P1049/NASA Glenn Research Center



Areas of AWT scheduled to be demolished are indicated by hash marks.
Support Image 5: CF: Drawing no. A-1, Demolition of Building 7 Altitude Wind Tunnel

Project Information: This report was part of a wider effort to document the Altitude Wind Tunnel prior to its demolition. This documentation was formally begun in May 2005 after Statement of Work 6.31 for the NASA Glenn History Program was finalized. The project includes the gathering of records, images, films, oral histories, and researching the facility, its tests, and significance. The resulting information is being disseminated via a book, website, multimedia cd-rom, documentary video, and this three-section construction report.

In 2005, NASA Glenn proposed to remove the entire Altitude Wind Tunnel circuit except for the test section within the high-bay of the Building 7. Building 7 and most of the other support buildings were not included in the demolition. Although the AWT was unique based on its sheer size alone, the maintenance costs for the facility became so high as to be justified only by the largest of research programs. Although mostly idle since the mid-1970s, this facility had a rich history and played an important role in NASA and aerospace history. For this reason NASA Glenn felt it was important to document the facility as thoroughly as possible before its destruction, and share the information with the public and within the agency.

Historians: Bob Arrighi Wyle Information Systems, Inc.
NASA Glenn History Program, Cleveland, OH

Date of Construction: The primary support buildings were built between 1942 and the end of the 1943. The frame of the Shop and Office Building was in place by September 1942 and the building was largely built by September 1943. The building's test section and control room were complete in January 1944. The Refrigeration and Exhauster buildings were completed in the fall of 1943. The facility conducted its first test run on February 4, 1944.[325] The Primary Pump House was added in 1951, and the Vacuum Pump House was constructed in 1961 and 1962, The Small Supersonic Wind Tunnels were built incrementally between 1945 and 1953.

Engineers: Alfred Young, Louis Monroe, Larry Marcus, Harold Friedman, Abe Silverstein, and others of the National Advisory Committee for Aeronautics.[326] Carrier Air Conditioning Company.

Contractors: Sam W. Emerson Company, Pittsburgh-DesMoines Steel Company, Carrier Air Conditioning Company, Collier, General Electric, York Refrigeration Company, Arthur E. Magher Company.[327]

Owners: The facility was originally constructed for the National Advisory Committee for Aeronautics' Aircraft Engine Research Laboratory. The lab became part of the National Air and Space Administration (NASA) on October 1, 1958. In March 1998 the center was renamed the John H. Glenn Research Center at Lewis Field.

Significance: The significance of the support buildings was their contribution to the operation of the Altitude Wind Tunnel (AWT) and Space Power Chambers (SPC) facility. The AWT was the only facility capable of testing full-scale engines in simulated flight conditions. It contributed greatly to the development of the early turbojet engines. The SPC was among the first large vacuum chambers in the nation. It was used extensively for the successful Project Mercury and Centaur rocket programs.

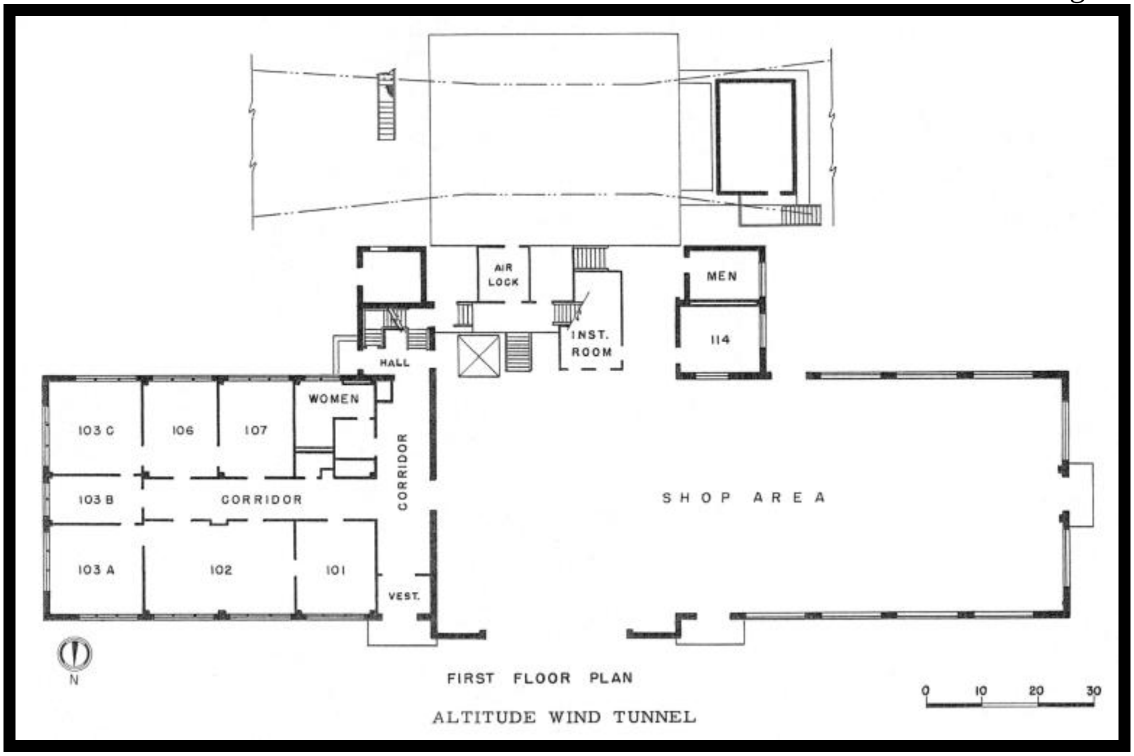
In addition, the refrigeration system was the largest in the world when it came online in the 1940s. It was capable of cooling millions of cubic feet of air in the AWT to -47 degrees F. It also continues to refrigerate the Icing Research Tunnel.

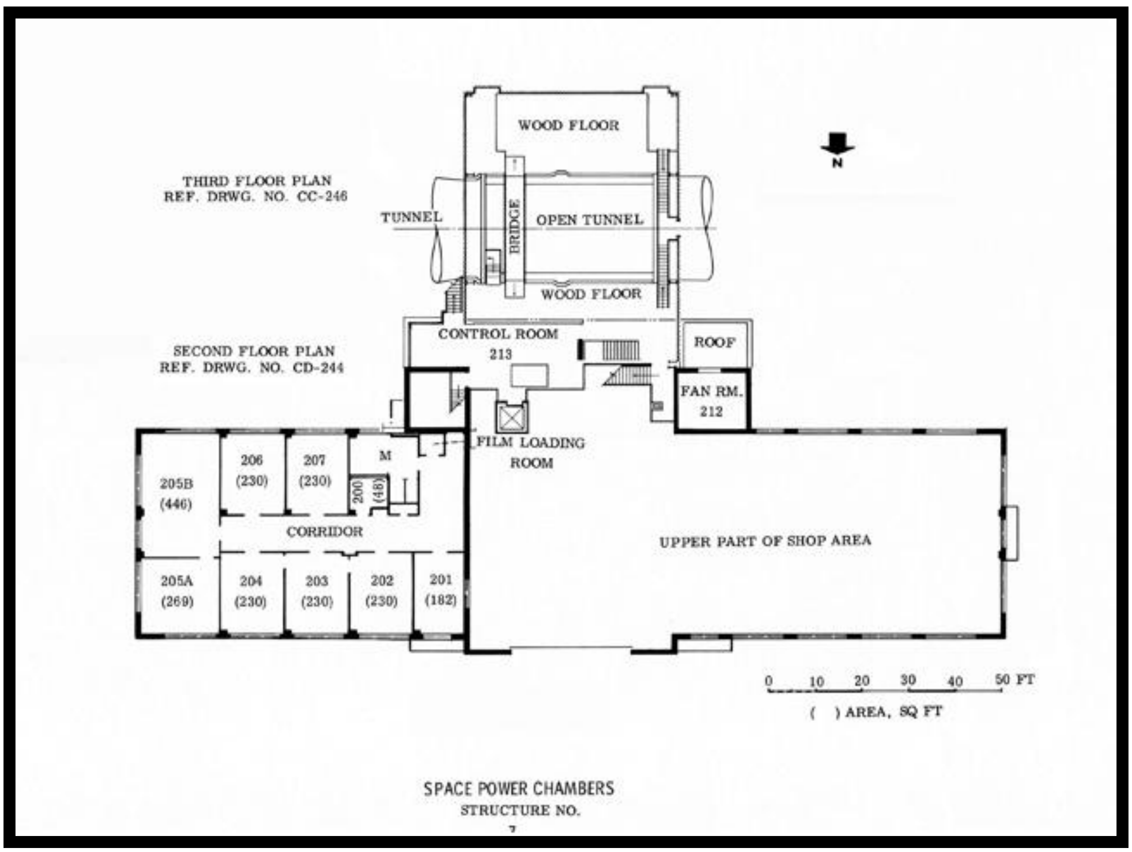
A. Shop and Office Building:

View from northwest of the Shop and Office Bldg. with the Shop Area in the foreground.
Support Image No. 6: 1944-05222/NASA Glenn Research Center (1944)

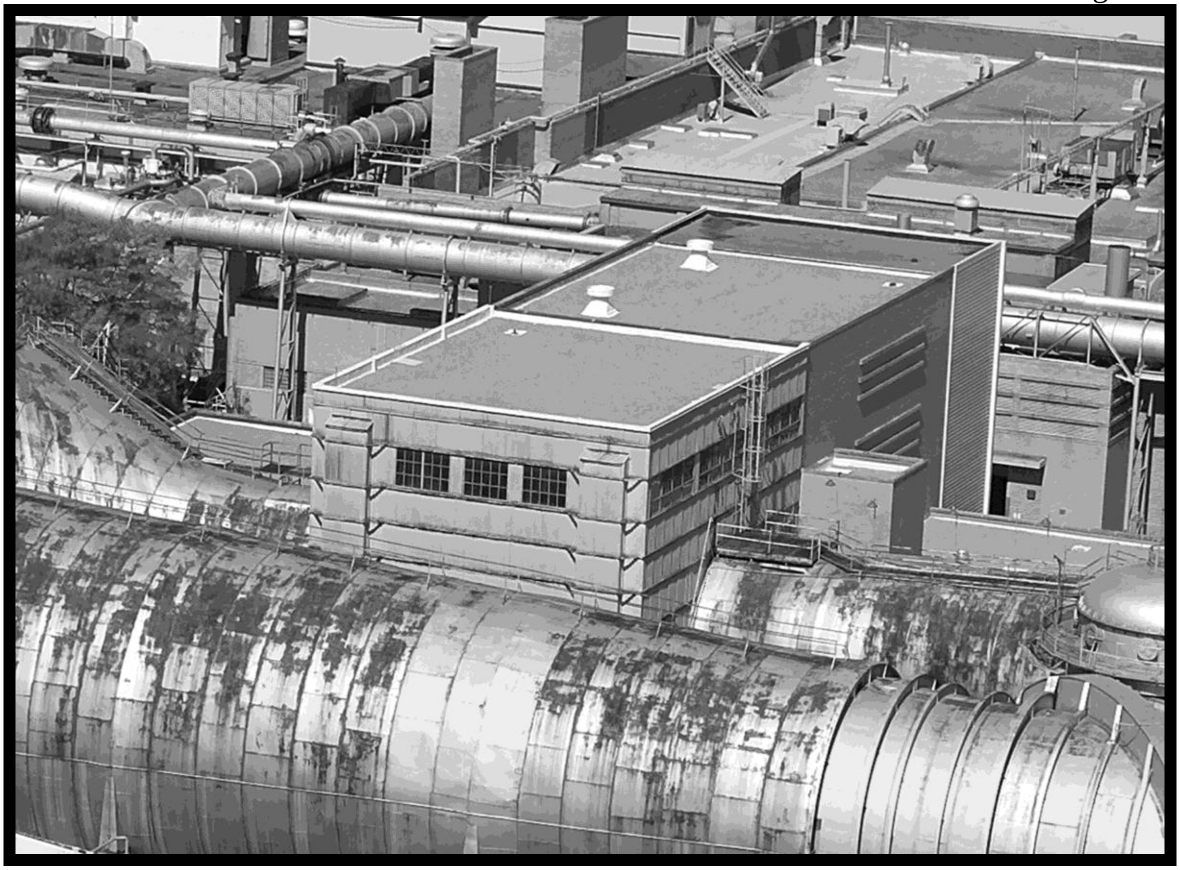
The Altitude Wind Tunnel (AWT) Shop and Office Building, Building 7, is a T-shaped building that serves as the facility's center. It housed the tunnel's test section, control room, instrumentation, shop, and offices. The entire width of the building was 185 feet 7 ¼ inches.[328] The height of central portion of the building is 63 feet 7.75 inches, and the wings are 28 feet 1.5 inches. This center section was much wider and taller than either of the wings.[329]

The east wing contains two floors of offices and the west wing consists of a large two story shop room. The three-story central portion of the building possesses two distinct areas. The northern front area, referred to as the high-bay, is constructed in the same style as the two wings. This section now contains the Near-Field Antenna Range. The southern, rear portion, referred to as the test chamber, was constructed separately. It contains the AWT viewing platform on the third floor, the test section between the second and third floors, and the balance chamber below the test section. In the early 1960s, a control room for Space Power Chamber No. 1 was constructed in the balance chamber. In the 1980s, the area was reconfigured again for the Far Field Antenna Facility.





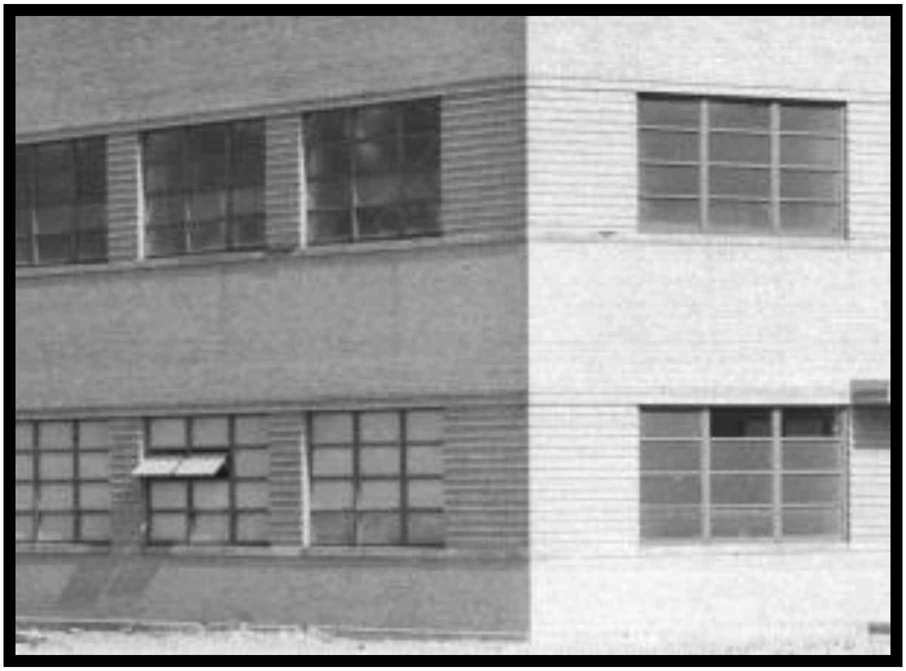
Support Images7 &8: Shop and Office Building Floor Plans/NASA Glenn Research Center (1967)



View from the south showing design differences in the test chamber and high-bay of the Shop and Office Bldg.
Support Image No.9: 2005-01483/NASA Glenn Research Center (2005)

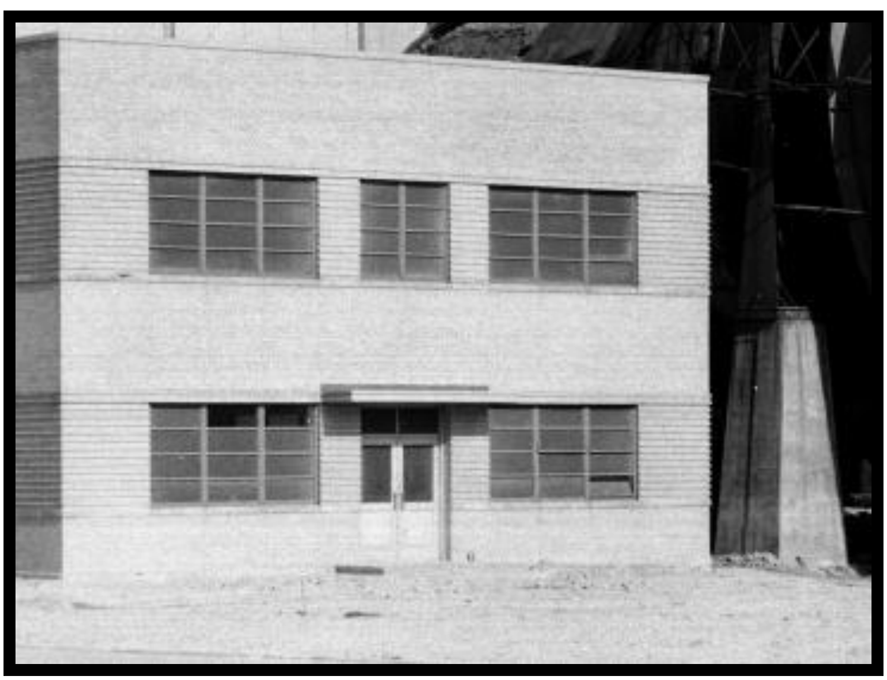
Building Exterior: The Shop and Office Building was constructed with the blonde face brick that matches the other buildings erected at the laboratory. Rustication of the bricks was used between and along the tops and the bottoms of the windows. Rustication is the staggering of the bricks or rows of bricks so that some bricks protrude further than others creating a pattern on the flat brick wall. The roof was edged with a limestone coping.[330]

The original banded window scheme was identical for both the east and west wings. There were four identical 5-foot 7.75-inch high 12-pane horizontal sash windows running the length of both the first and second floors. The second floor also contained a narrower 8-pane window near the center section. Below these on the east and west wing first floors were sets of metal and glass entrance doors. Two concrete steps led to the doors, and concrete canopies were overhead. The rows of windows in the wings have a continuous limestone sill along the bottom.[331] The building received a major rehabilitation in 1974 which included new windows, entrances, and other modifications.



Original sash windows and rustication pattern in the brick on exterior of the Shop and Office Building Support Image No. 10: 1944-05222/NASA Glenn Research Center (1944)

The west-facing side of the building had a window design similar to the north side. There were identical wide windows to the north and south of both floors with a narrower window in the center of the second floor. A metal and glass pedestrian entrance under a canopy was in the center on the first floor.[332] The building's eastern side was identical to the western except the doorway was replaced a narrow window identical to that on the second floor. [333]

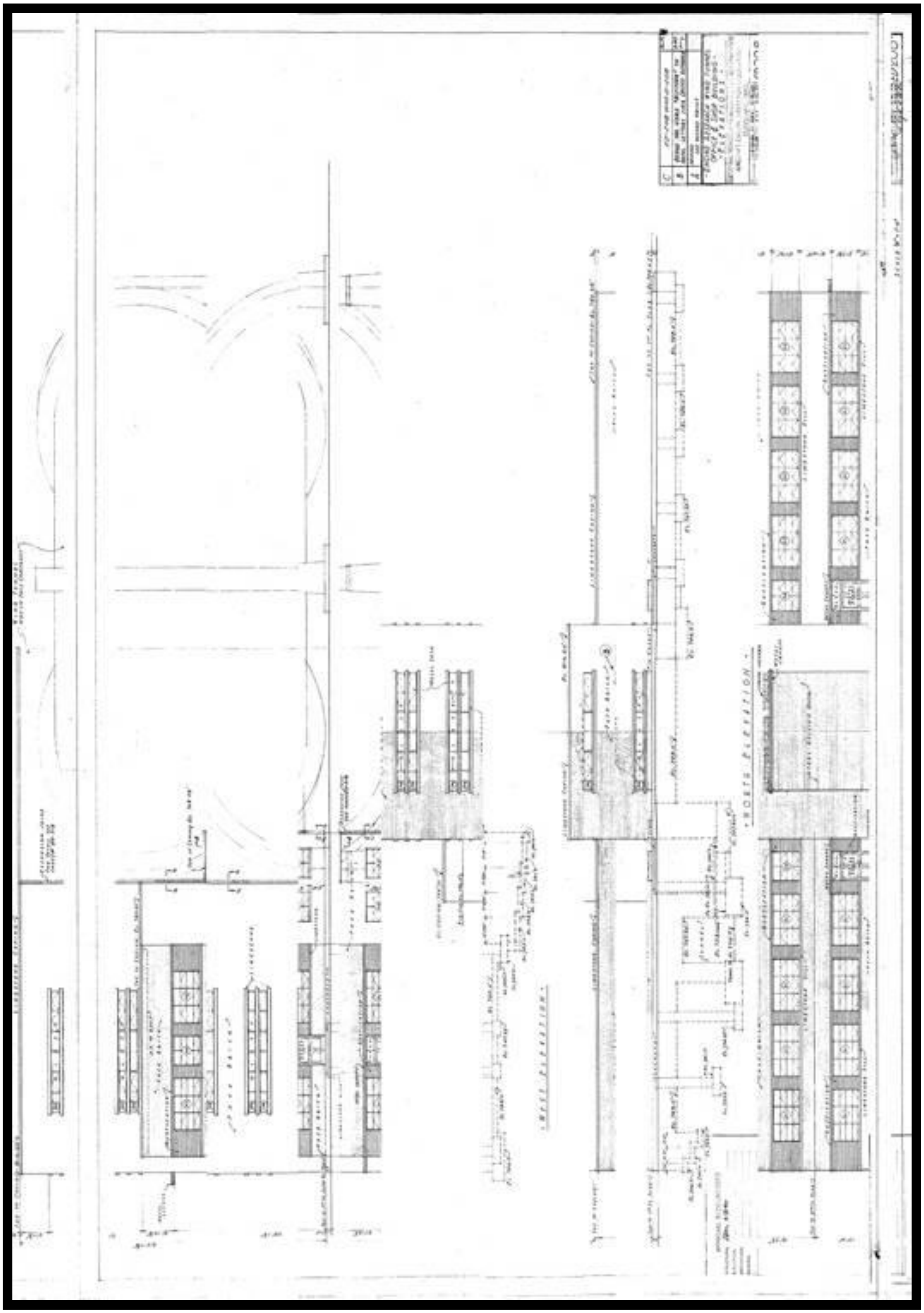


Original west-facing exterior of the Shop and Office Bldg. The eastern end is similar without the doorway.

Support Image No.11: 1944-05222/NASA Glenn Research Center (1944)

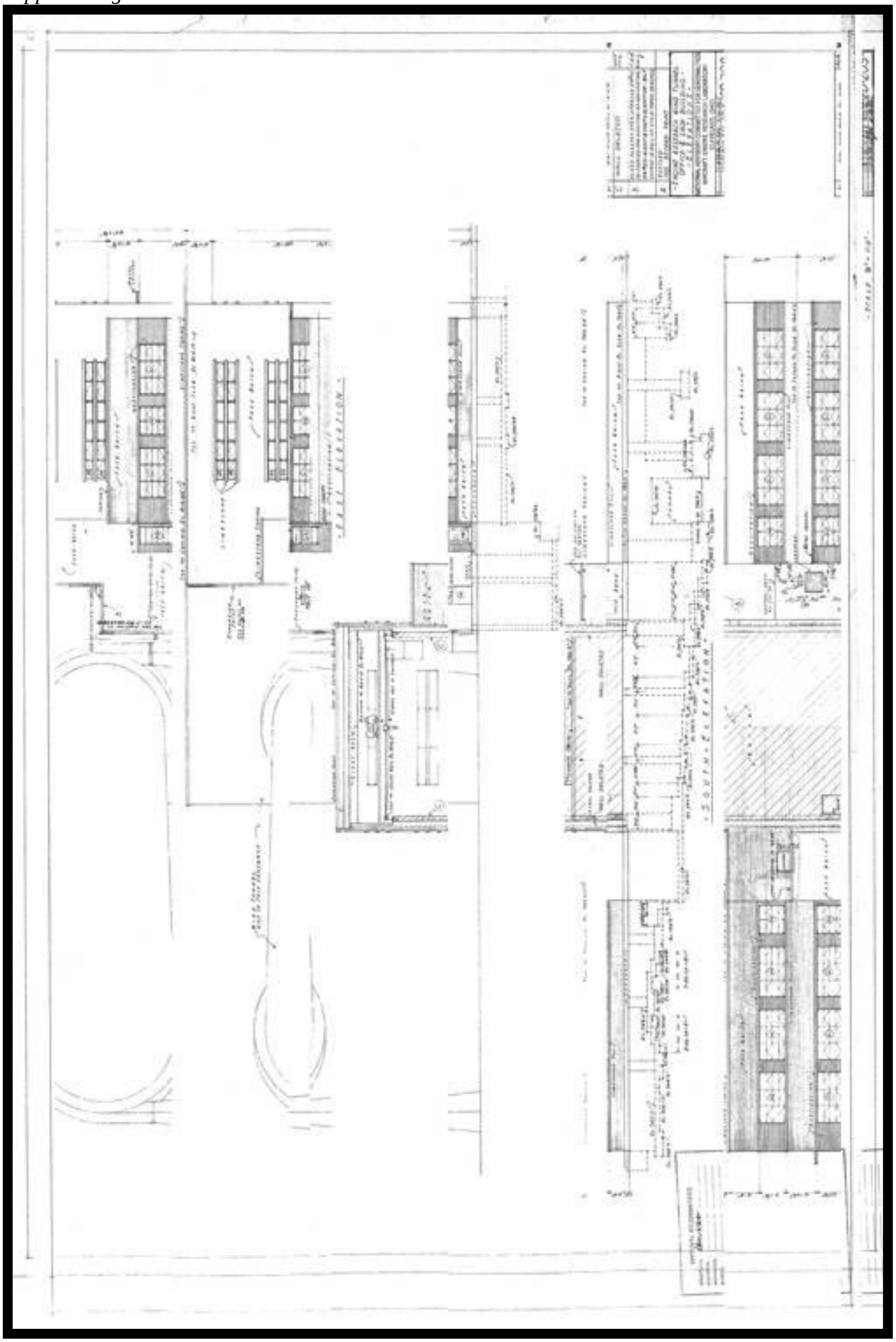
The high-bay had 3 sets of 12 windows vertically aligned on the upper levels of the north, east, and west walls. Each set was banded at the top, middle, and bottom with limestone coping.[334] A large truck entrance with a steel rolling door occupied the center area on the front north side providing direct access to the high-bay that ran from the front to rear of the building.[335] The front of the high-bay was expanded in the early 1990s. The truck door was relocated to the west wall of the shop area, and the front façade was enclosed in 1990. The original front pedestrian doorways were immediately to the east and west of the truck door. There was also a pedestrian entrance centered in the western wall of the shop area.

View from northwest of original high-bay exterior with truck and pedestrian entrances
Support Image No.12: 1944-05222/NASA Glenn Research Center (1944)



Elevation drawing of Shop and Office Building

Support Image 13: E 208 01 C/NASA Glenn Research Center



Elevation drawing of Shop and Office Building

Support Image 14: E 209 01 C/NASA Glenn Research Center

Chamber Exterior: The test chamber is in the rear of the high-bay and has a design unique from the rest of the Shop and Office Building. The exterior walls are covered with transite. There are five bands of the material running horizontally around the building. A narrower band runs along the uppermost portion. Later when the rear overhang was lowered, two additional bands of sheeting were added. Two parallel corrugated metal coverings ran vertically down the south side of the building to shield pipes. There are three 12-pane square windows along top of the south wall, and three longer 36-pane windows along the top of the east and west walls. The 20-foot diameter throat section of the wind tunnel penetrates the west wall of the test chamber on the second floor level and exits the east wall.

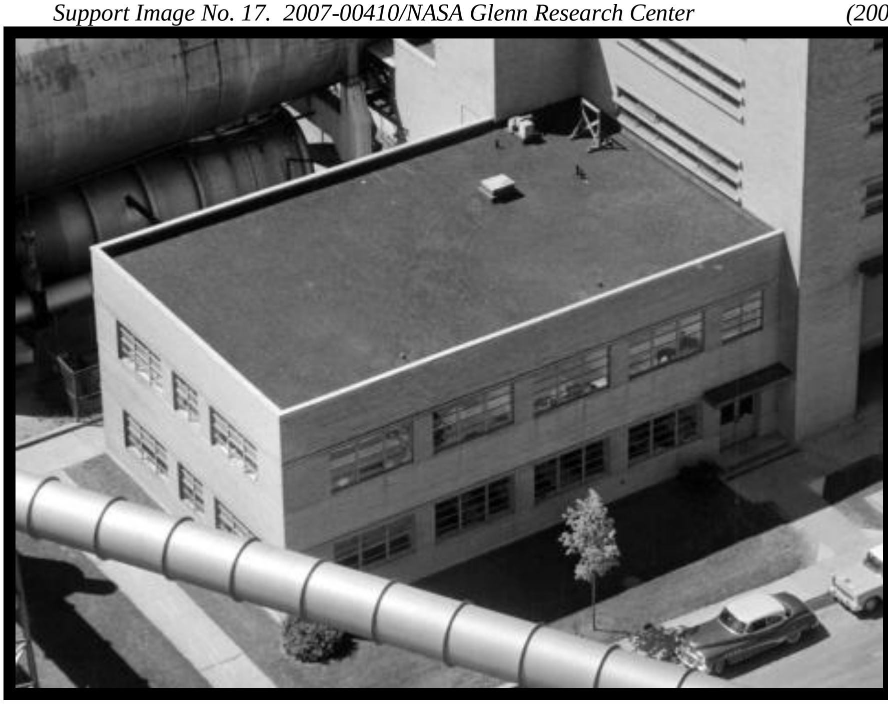
View from west of exterior test chamber in the Shop and Office Building
Support Image No. 15: 1945-10533/NASA Glenn Research Center
(1945)

In the rear of the building the second floor of test chamber portion of the building overhangs the first and is braced by steel supports. Beneath the overhang were nozzles and plumbing for a large carbon-dioxide tank resting on the ground. At some point the overhang was lowered. This was presumably done for the addition of the Space Power

Chamber No. 1 control room in the early 1960s. Metal braces jut out from the bottom of the overhang on the east and west sides and was attached to the side of the tunnel.

View from east of test chamber overhang in the rear of the Shop and Office Building
Support Image No.16: 2005-01482/NASA Glenn Research Center (2005)

View east inside a room on south wall of test chamber next to the tunnel test section
Support Image No. 17. 2007-00410/NASA Glenn Research Center (2007)



View from northeast of the exterior of the Shop and Office Building's office wing.
Support Image No.18: 1955-38784/NASA Glenn Research Center (1955)

Office Wing: The eastern wing is separated from the other areas of the Shop and Office Building. This office wing was 61 feet 1.75 inches long and 44 feet 8 inches deep. The first floor originally contained two small offices and a restroom on south wall, one large and one small office on the north wall, and a long office that ran the entire length of the east wall. A north/south entrance vestibule entered just to the east of the wall separating the wing from the high-bay. There was a slight extension off the rear of the building that included a stairwell and storage room in the eastern rear corner and restroom and foreman's room in the western rear corner.[336]

The second floor originally included four small 13-foot 5-inch by 17-foot 2.75-inch offices along the north side and a long 16-foot 9 7/8-inch office that ran the entire length of the east wall. The south side included a large 27-foot 2-inch by 17-foot 2.75-inch office and a small1 4-foot 5.25-inch Fan Room. Directly to the south of that was an 8-foot 2-inch wide dark room, and restroom. Access was provided by a stairwell in the south/center corner and a 3-foot 9-inch wide hallway that extended north into the center of the wing and east through the offices.[337]

During the Space Power Chamber period, the first floor offices were combined and enlarged. There were three offices along south wall, three along north wall, one small one in center of east wall.[338] The second floor remained the same except for the long office along east wall that was divided into two.[339] This layout has remained unchanged since the early-1960s.

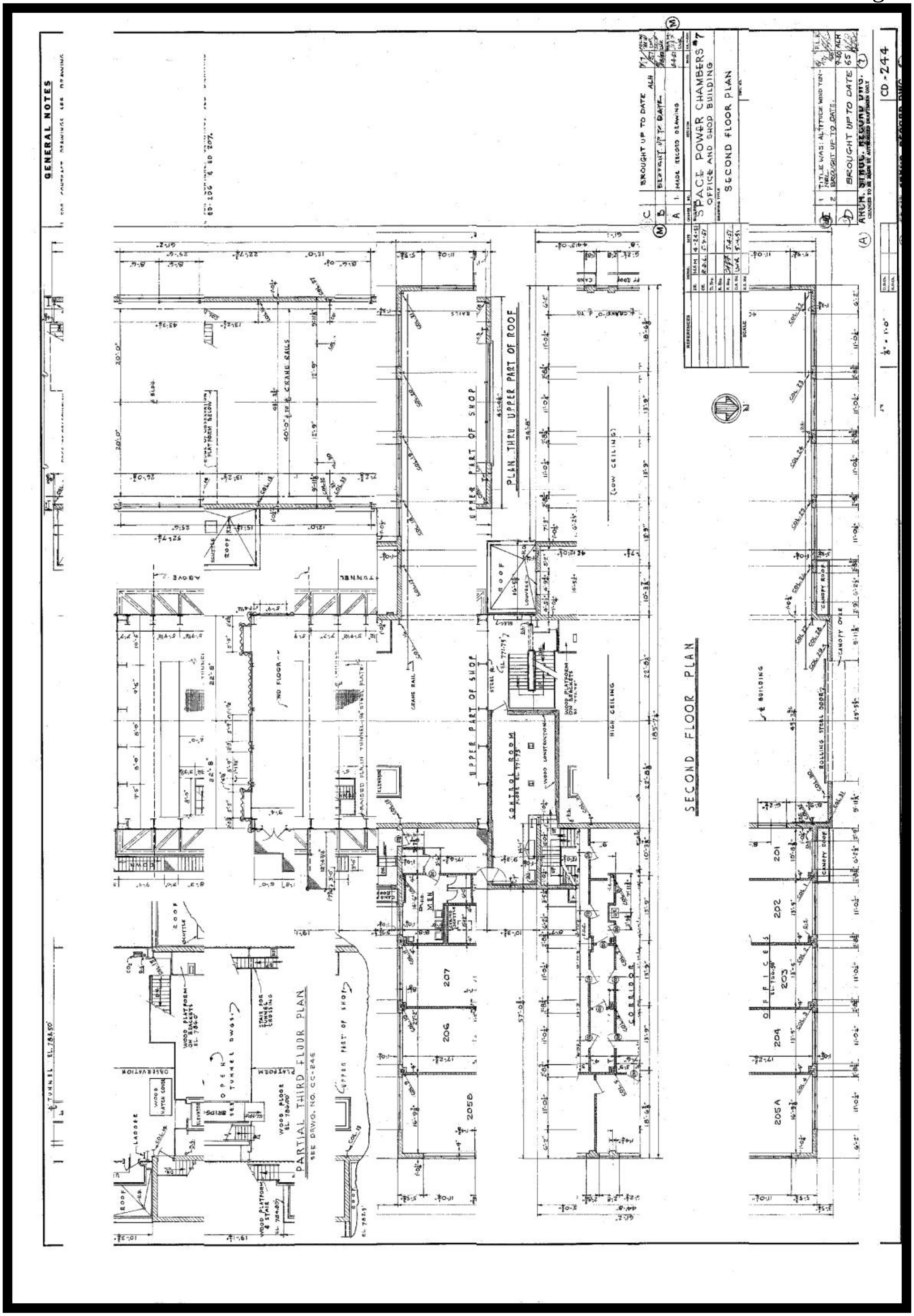
In 1973 and 1974 the Office and Shop Building underwent a major rehabilitation. The original multi-paned sash windows were replaced with large single-paned windows with aluminum frames. New communications systems were installed, walls were repainted, the roof was repaired, new vents were installed, new office doorways put in, and chalkboards were removed from the offices. [340]

View eastward down first floor hallway in the office wing of the Shop and Office Building
Support Image No. 19 : 1974-00351/NASA Glenn Research Center (1974)

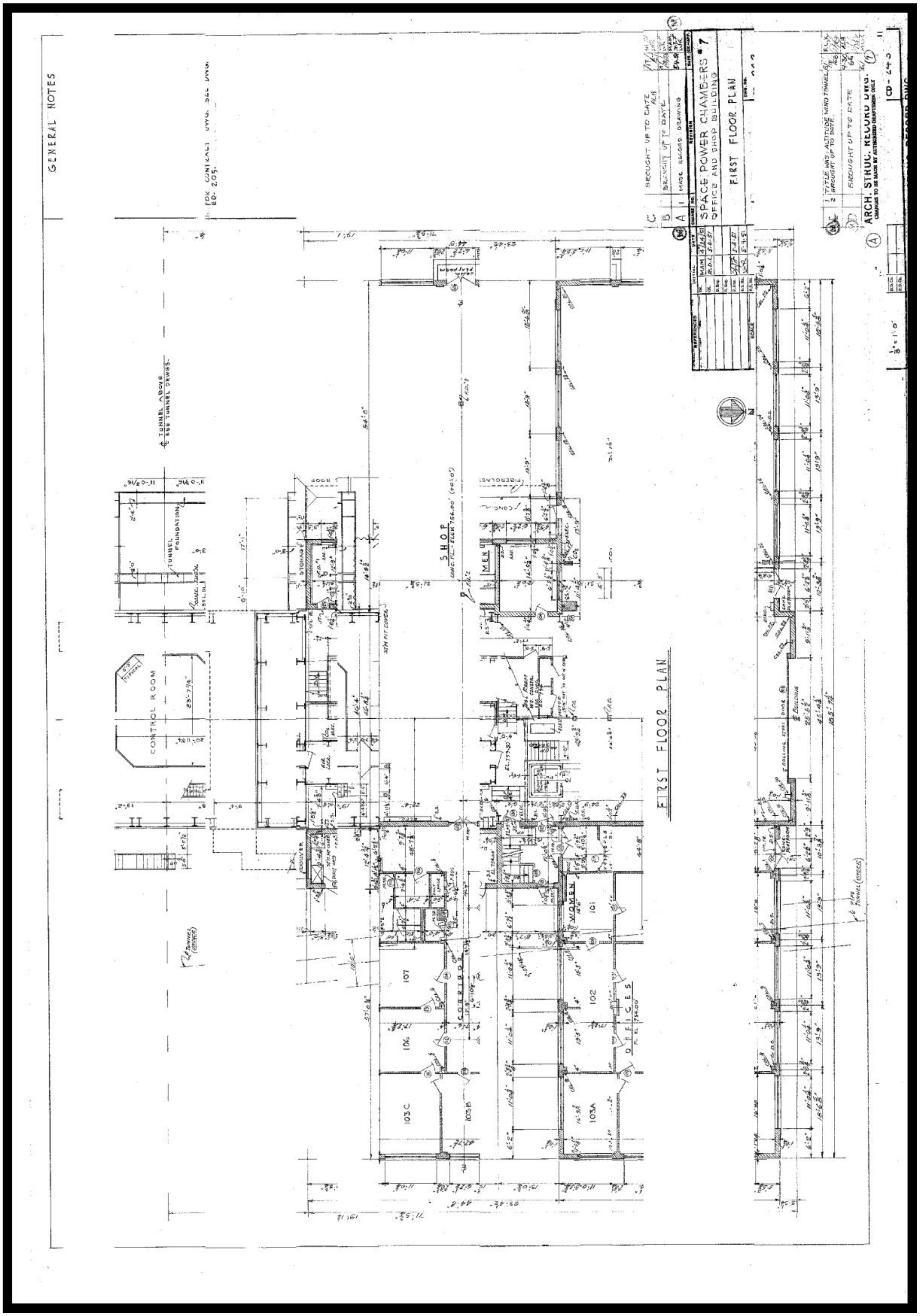
View north of original entrance vestibule in office wing of the Shop and Office Building.
Support Image No. 20: 1972-00990/NASA Glenn Research Center (1972)

Interior of an office with original windows in the office wing of the Shop and Office Building.
Support Image No. 21: 1972-00987/NASA Glenn Research Center (1972)

New windows and light fixtures after the 1974 renovation of the Shop and Office Building.
Support Image No. 22: 1974-00353/NASA Glenn Research Center (1974)



Drawing of Shop and Office Building during 1960s
Support Image 23: CD 244 01 E/NASA Glenn Research Center


GENERAL NOTES
SPACE POWER CHAMBERS #7
OFFICE AND SHOP BUILDING
FIRST FLOOR PLAN
CONTROL ROOM
SHOP
MEN
WOMEN
CORRIDOR
OFFICES
FIRST FLOOR PLAN
ARCH. STRUC. RECORD DWG.

Drawing of Shop and Office Building during 1960s
Support Image 23: CD 243 01 E/NASA Glenn Research Center

Shop Area: The shop area is an open two-story space that occupies the entire western wing of the Shop and Office Building and opens up into the center high-bay area. It is 44 feet 8 inches wide and 42 feet 7.5 inches deep.[341] This large area was originally kept relatively empty except for a few workbenches and temporary test stands. A small office was located off the southwest corner of the room with access provided via the high-bay area.

The ceiling and walls were unfinished with pipes, tresses, and ducts exposed. A large ventilation duct ran along the south wall. Rows of fluorescent light fixtures were hung from the ceiling.[342] There were double glass and metal doors on the north and west walls for pedestrian entrance. There were originally nine 12-paned sash windows distributed along the north wall and four on the west wall with another 8-paned window above the door.

View facing southwest of the shop area in the AWT Shop and Office Building showing overhead crane
Support Image No. 25: 1972-00979/NASA Glenn Research Center
(1972)

The shop area was used to build and disassemble engines prior to and after their test runs in the AWT. An overhead two-rail crane ran east and west and could transport items to and from the high-bay. Besides moving items east and west, the crane could move north and south along its cross rail allowing access to any area in the shop.

As part of 1991 project that included modifications to the Engine Research Building loading dock, the north face of the Office and Shop Building was expanded northward. The first floor of the Shop Area was expanded 19 feet. The 24-foot 9-inch section closest to the high-bay was extended and additional 5 feet 3 inches to make it even with the high-bay. A new concrete apron was placed outside the doorway on the west wall.[343] The expansion resulted in two new offices, a large control room and smaller computer room along the north wall. The exterior of the offices was had a low roof. A stand alone office was built inside the shop area near the high-bay. [344]

Original first floor shop office with the main shop area visible through window and doorway
Support Image No. 26: 1972-00974/NASA Glenn Research Center (1972)

In June 1961, a canister-like trailer designed for the Mercury Evaporating Condensing Analysis (MECA) experiment was installed in the southwest corner of the shop. Double doors provided access to one end and four viewing portals ran lengthwise along each side the trailer. The rear of the trailer had a large exhaust pipe. Inside a work table was set up with a mercury collector at one end connected by a narrow condensation tube to a boiler.

The trailer was removed after the tests, and an exhauster hood was installed in this same area by 1972.[345] In the mid-1970s the shop was used as a garage and work area for the center's electric automobile research. Every model electric vehicle available was tested.

Mercury Evaporating Condensing Analysis facility installed in southwest corner of shop area
Support Image No. 27: 1961-57173/NASA Glenn Research Center (1961)

Electric vehicle research in shop area during the mid-1970s
Support Image No. 28: 1977-01813/NASA Glenn Research Center (1977)

<u>High Bay:</u> This three-story 42-foot wide by 52-foot 7.25-inch long high-bay area was used to transport test articles between the shop area in the western wing of the building and the test section in the rear.[346] The test articles were transported back and forth using an overhead 10-ton Shaw-Box crane ran the length of the high-bay.

The crane continued rearward into the open test chamber area on the second floor.[bb] Originally there were no walls between the high-bay and the shop or the upper level of the test chamber. A brick wall separated the high-bay from the office wing. There was a window in the wall that provided a view of the truck door, high-bay, and shop from the northwest second floor office.[347] The large open spaces in the high-bay and shop areas were used to set up displays for various tours and inspections.

[bb] For a description of the test chamber area see the Altitude Wind Tunnel Architectural section of this report.

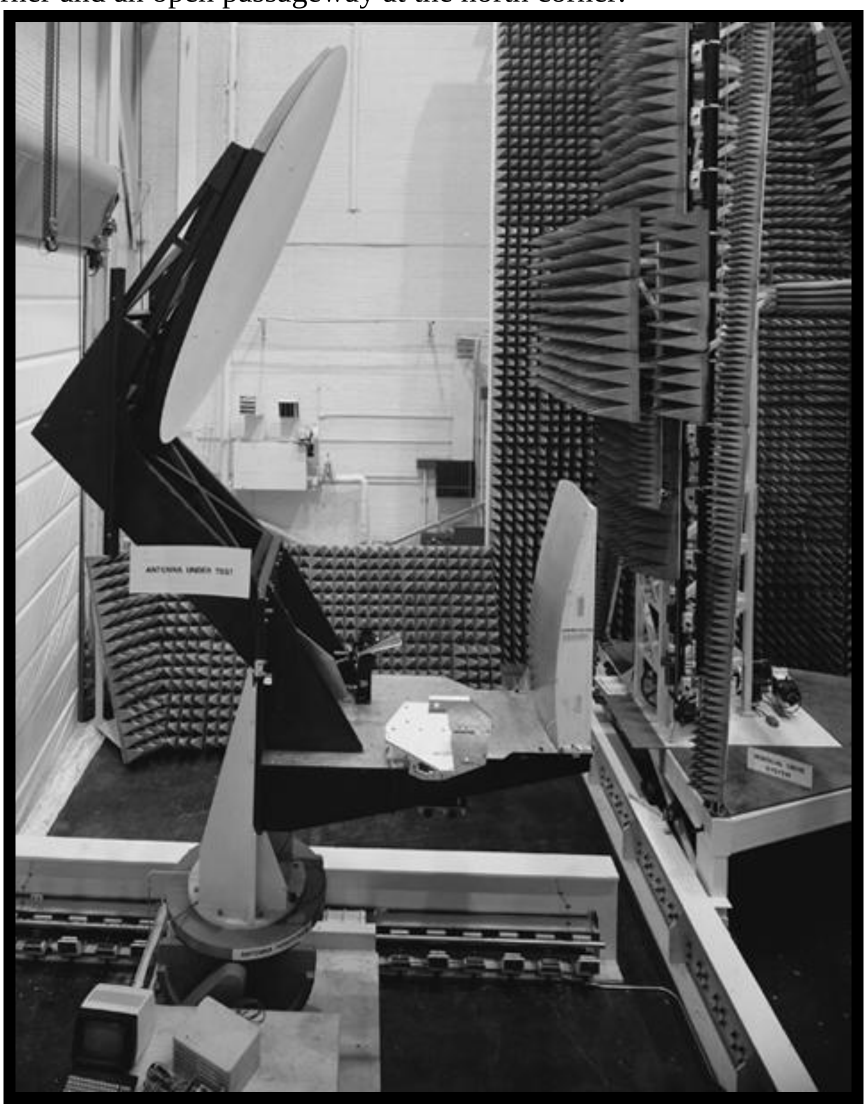
View of interior of high-bay where it connects with the Shop Area in the Shop and Office Building
Support Image No.29: 1972/NASA Glenn Research Center (1972)

View facing east of the high-bay with window to office wing and elevator and at right stairs to the test chamber
Support Image No.30: 1945-10599/NASA Glenn Research Center
(1945)

Overhead 10-ton crane that ran from high-bay into the test chamber

Support Image No. 31: 2007-00401/NASA Glenn Research Center (2007)

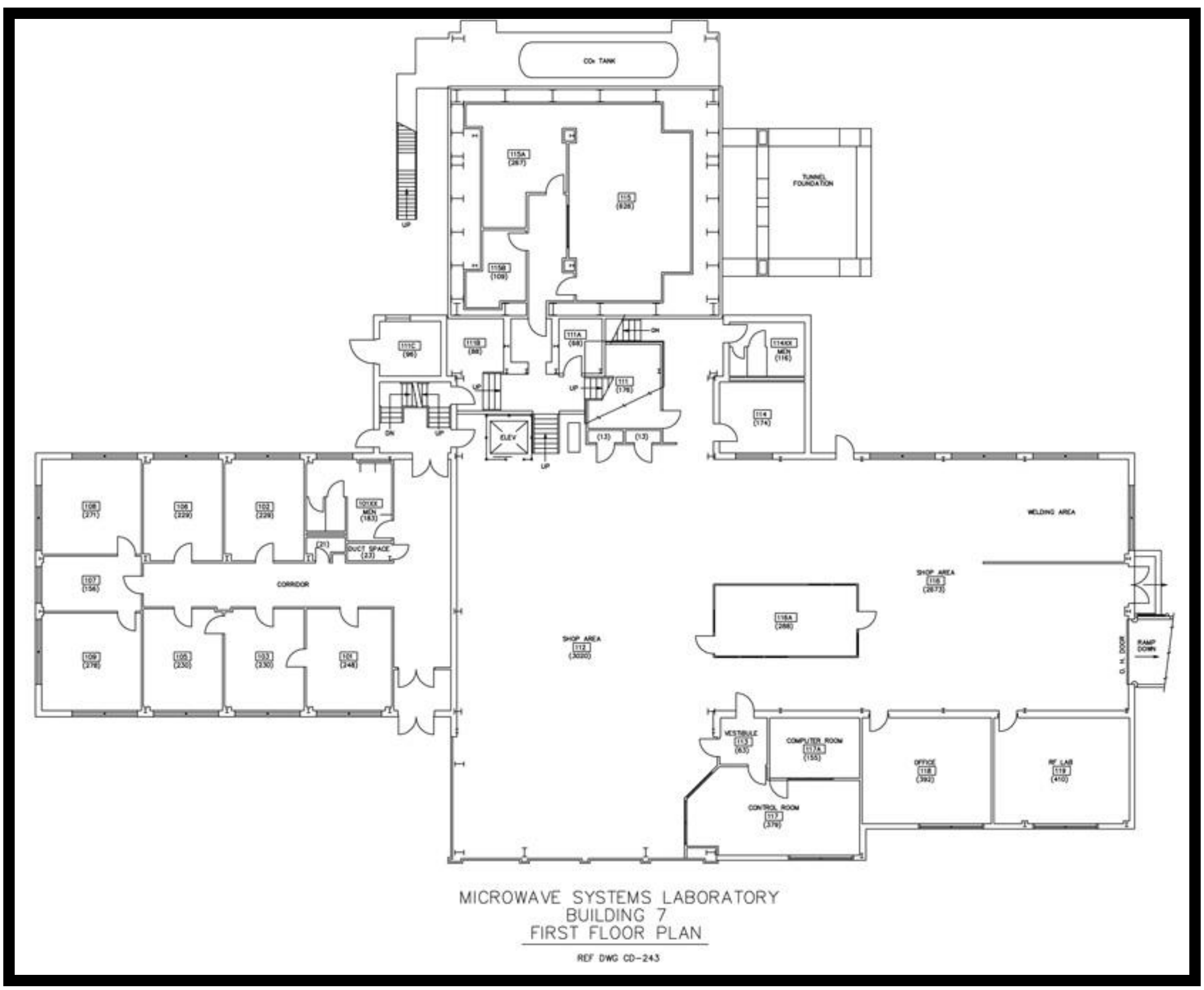
The shop and high-bay were converted into the Microwave Systems Laboratory (MSL) in the early 1980s as the proposed rehabilitation of the tunnel was being considered. The MSL consisted of the Near-Field Test Facility and the Far-Field Test Facility. In 1983 the high-bay was sealed off from the rear test section area. U-shaped 36-foot high anechoic walls and radio frequency absorbing walls were built in the rear of the high-bay. These walls, covered with row after row of foam pyramids to absorb any microwave rays that escaped the antenna, provided a more precise test atmosphere for researchers to scan a 22-by 22-foot area from just a few thousandths of an inch away from the surface. [348]This resulted in the complete blocking of the test section area to the south, and the partial blocking of the shop area to the west. The brick wall to the east has always separated the room from the office wing. There remained access to the high-bay from the shop via a pedestrian door at the south corner and an open passageway at the north corner.[349]



Near-Field Antenna Facility installed in the high-bay area of the Shop and Office Building
Support Image No.32: 1984-00746/NASA Glenn Research Center (1984)

Originally there was a large truck door in the center of the north wall that was used to bring hardware, equipment, and test vehicles into the facility. In 1991 this truck entrance was sealed, and the 45.5-foot wide high-bay was extended outward 20 feet 9 inches. The first floor of the Shop Area was also extended at this time. A new concrete apron was placed outside the doorway on the west wall.[350] The exterior of the high-bay extension is covered with horizontal white metal panels that were framed by five vertical steel supports. [351]

The addition of 2400 square feet of floor space enabled larger antenna systems to be tested. The Shop addition was used for a small radio frequency laboratory, a Near-Field scanner control room, and office. The new office and laboratory space facilitated the integration of the Near-Field and Far-Field antenna groups. The rehab included associated structural, mechanical, and electrical modifications.[352] In 2004 there was a new effort to rehab the interior of area between the high bay and test section. The hallway and first floor offices were modernized.



Drawing of Building 7 after its conversion into the Microwave Systems Lab and the expansion of the shop
Support Image No. 33: CF-106745/NASA Glenn Research Center
(1992)

View of wall built between high-bay and test chamber for Near Field Antenna Facility
Support Image No. 34: 2007-00400/NASA Glenn Research Center (2007)

View from north of the 1991 extension of the high-bay and shop area
Support Image No.35: 2007-02581/NASA Glenn Research Center (2005)

Control Room and Other Areas:

There is a 23-foot, 4-inch long and 73-foot, 10-inch wide area between the high-bay and the tunnel's test section. This three level area is linked vertically by an elevator and flight of stairs. The ground level of this area had an Instrumentation Room, air lock into the tunnel's balance chamber, a restroom, and several other small rooms. Adjacent to the east of this area is a 10-foot 3-inch by 12-foot, 4-inch steam pit. The east end of this first floor area connects to the eastern office wing of the building via both a stairwell to the second floor and a doorway leading to the building's first floor foyer. By 1992 the first floor rooms below the test section area were remodeled and used for the Far Field Antenna Facility.[353]

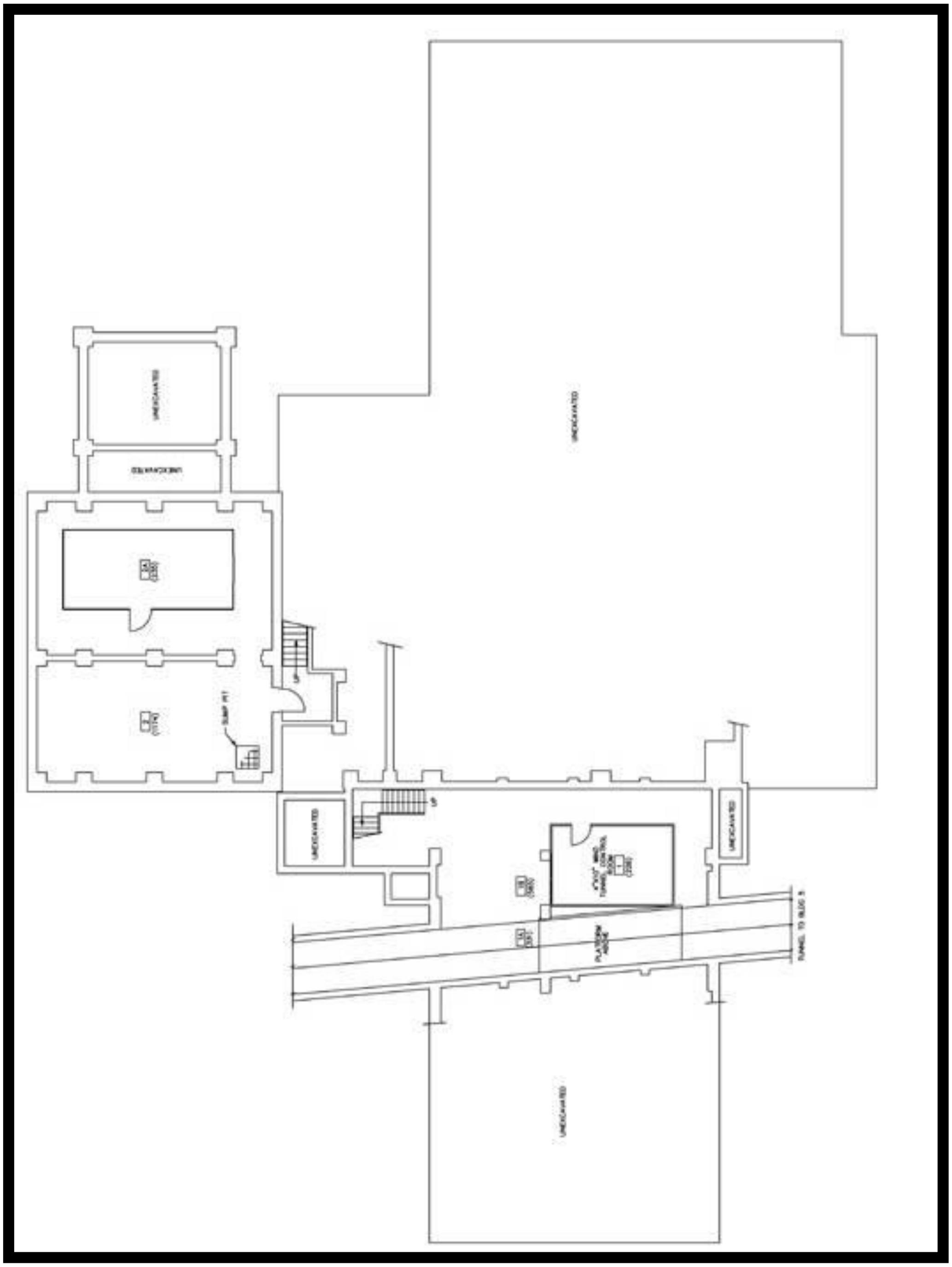
There is an open stairway between located between the high-bay and the second floor test chamber. To the south of this stairway on the mezzanine level was the 12 foot 4 ¾ inch by 10 foot 3 ¾ inch control room. This was later expanded in 1965.[cc] On the shop area side, there was a 14 foot 9 ½ inch by 10 foot 3 ¾ inch section of roof and Fan Room opposite of where the control room is located.[354]

Original AWT control room inside the Shop and Office Building
Support Image No.36: 1946-14588/NASA Glenn Research Center (1946)

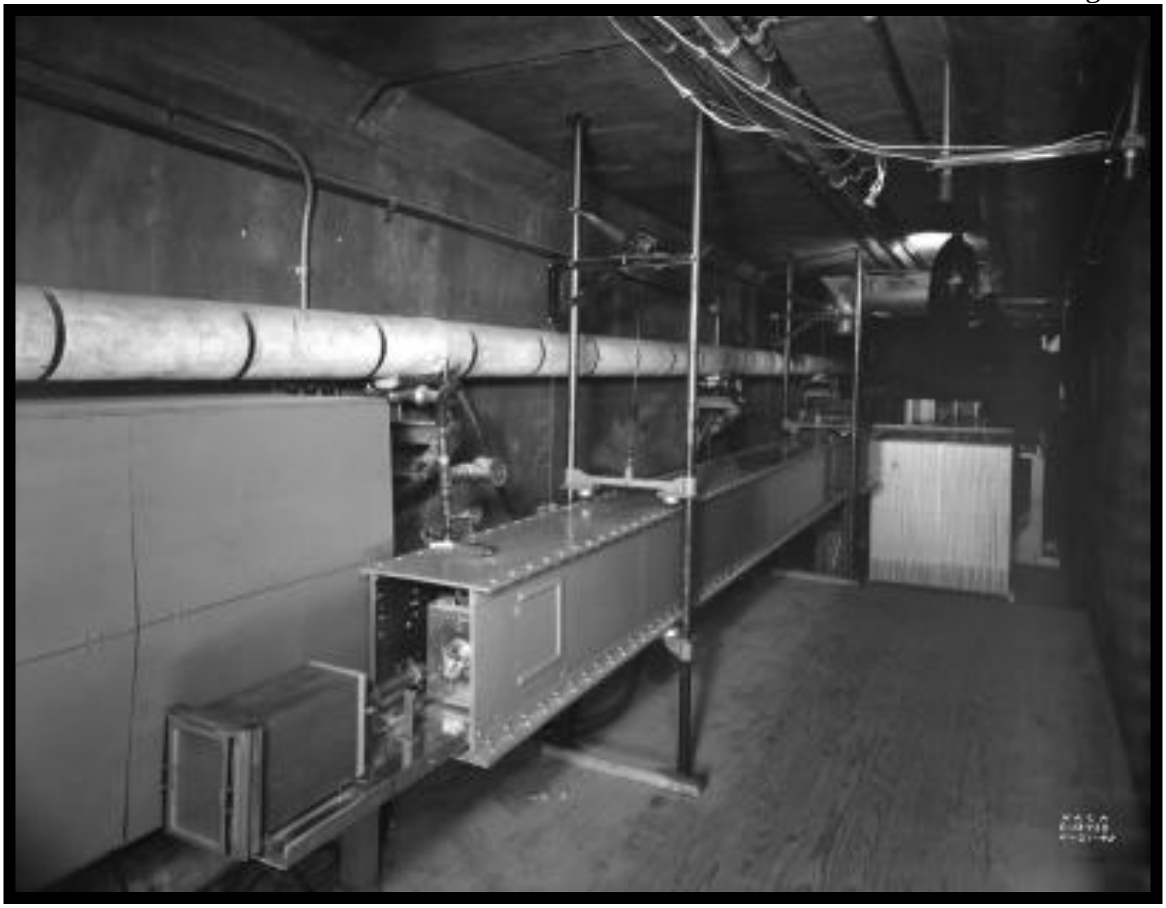
[cc] For a detailed description of the control room see the AWT Architectural Information section of this report.

Hallway at rear of office wing. Stairs leading to basement and second floor of offices.
Support Image No. 37: 1974-00352/NASA Glenn Research Center (1974)

<u>Basement:</u> The ground below the shop, high-bay, and offices was largely unexcavated. There was a corridor that ran beneath the front pedestrian door to the back of the building. This corridor included a pedestrian tunnel that connected the AWT to the Engine Research Building. Adjacent to this was an area used for the Duct Lab wind tunnel. Underneath test section are two large storage rooms only accessible via a stairwell to the first floor.[355]



Basement floor plan showing excavated areas and Duct Lab tunnel
Support Image No.38: CF-106744/NASA Glenn Research Center *(1992)*



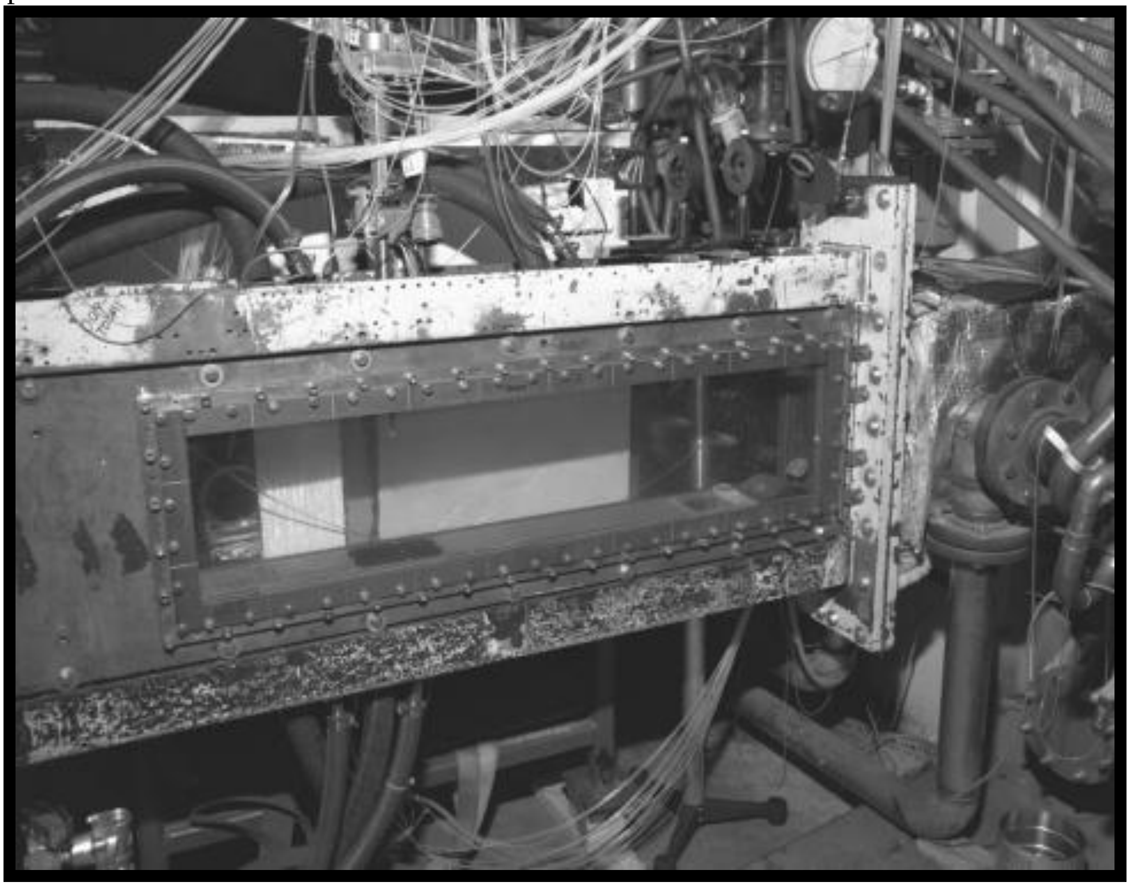
Basement corridor with Duct Lab beneath Shop and Office Building
Support Image N. 39. : 1945-13738/NASA Glenn Research Center (1945)

<u>Duct Lab:</u> A small supersonic wind tunnel called the Duct Lab was created in the AWT's basement corridor. The tunnel is primarily used for flow physics and supersonic injector studies. Originally constructed in 1945 to take advantage of excess AWT vacuum capabilities, the tunnel was still in operation in 2007. It can reach speeds of Mach 1.6 to Mach 5.0 and temperatures of 400° F.[356] The original control was replaced by a new control room was in 1974.[357] The control room was rehabbed in 1990 as part of the expansion of Building 7.[358]

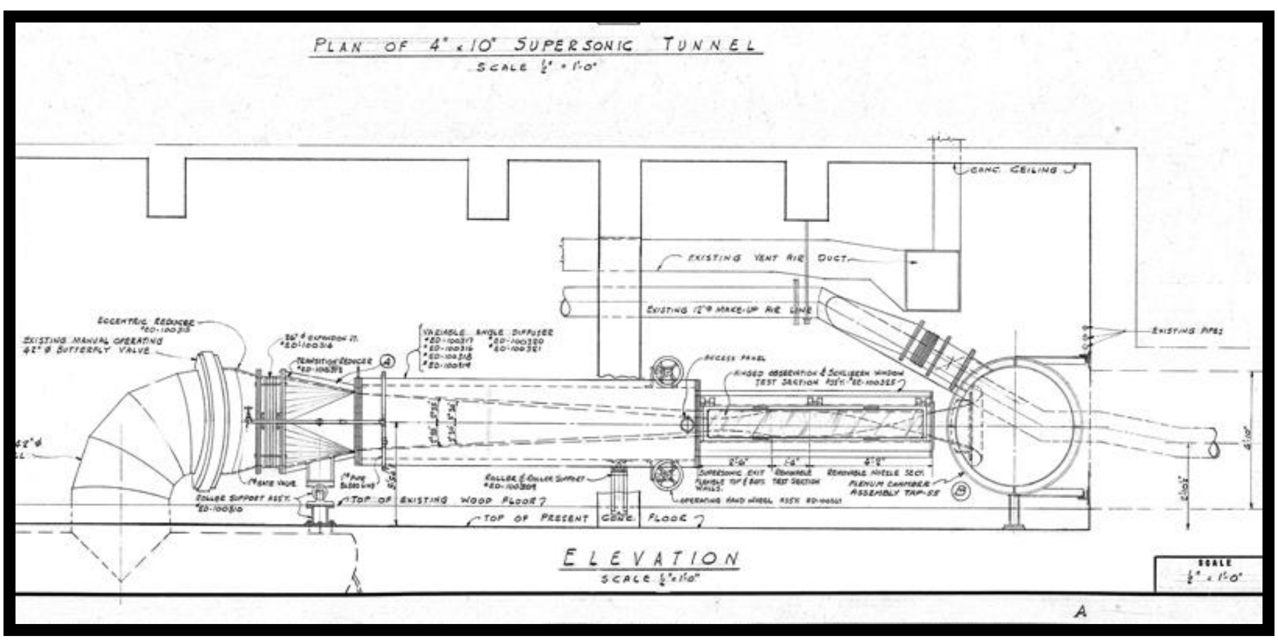
The 8-foot long, 4-inch wide, and 10-inch high test section includes a hinged window for observation and to operate Schlieren apparatus. The removable Plexiglas or steel windows include rows of pressure taps. [359]

The AWT's exhausters drew the air through the tunnel via 42-inch diameter duct that exited through the floor. This was later expanded to a 48-inch bellmouth. Heated make-up air entered a plenum chamber just upstream from the test section. [360] A removable 50-foot long nozzle accelerated the air speed. After the model was a 30-inch long flexible wall.[361]

Following the test section was an 11-foot 7-inch long variable angle diffuser which expanded to 22 7/8 inches in width.[362]



Duct Lab 4-by 10-inch wind tunnel in the basement corridor beneath Shop and Office Building
Support Image No. 40: 1995-00598/NASA Glenn Research Center
(1995)



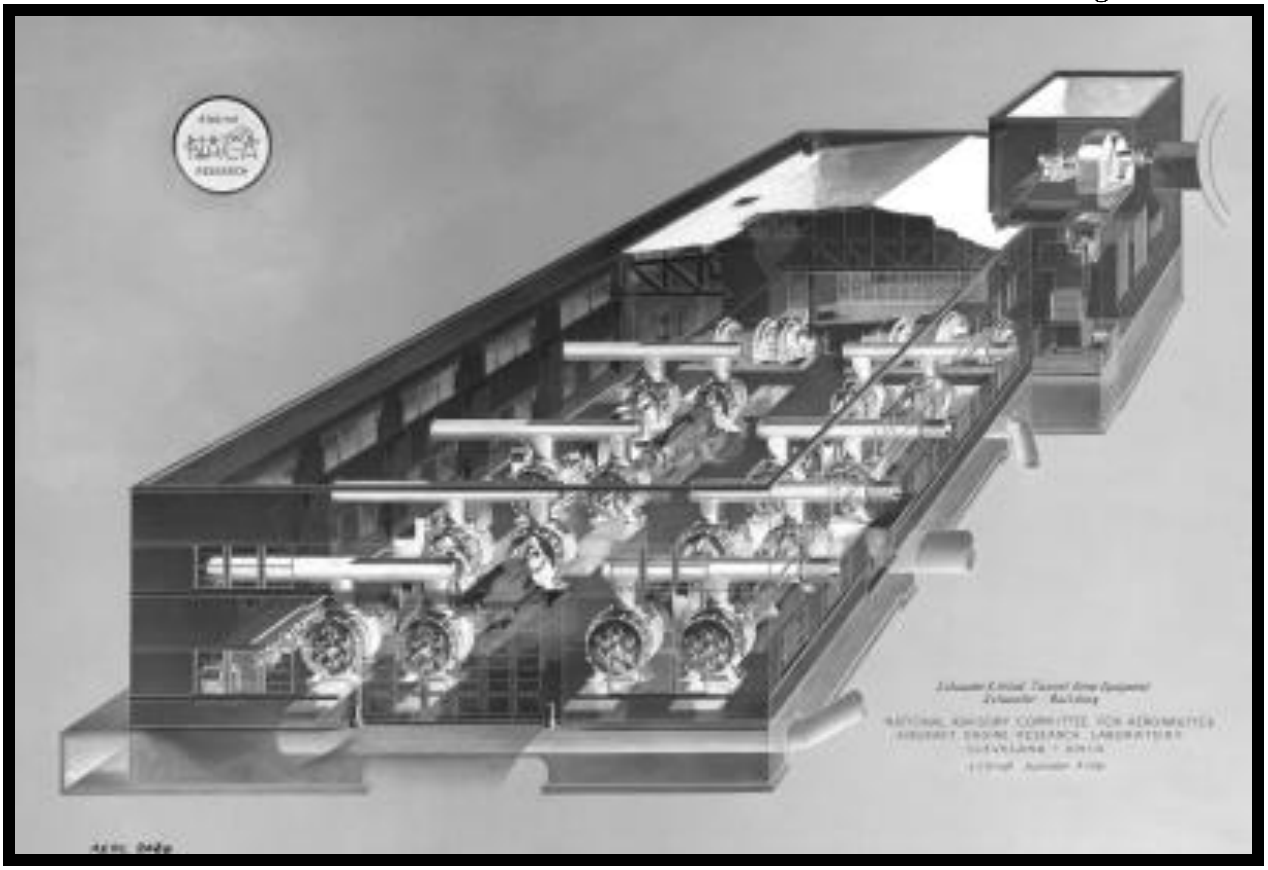
Elevation drawing of the Duct Lab supersonic wind tunnel
Support Image No.41: ED-100300/NASA Glenn Research Center

B. Exhauster Building:

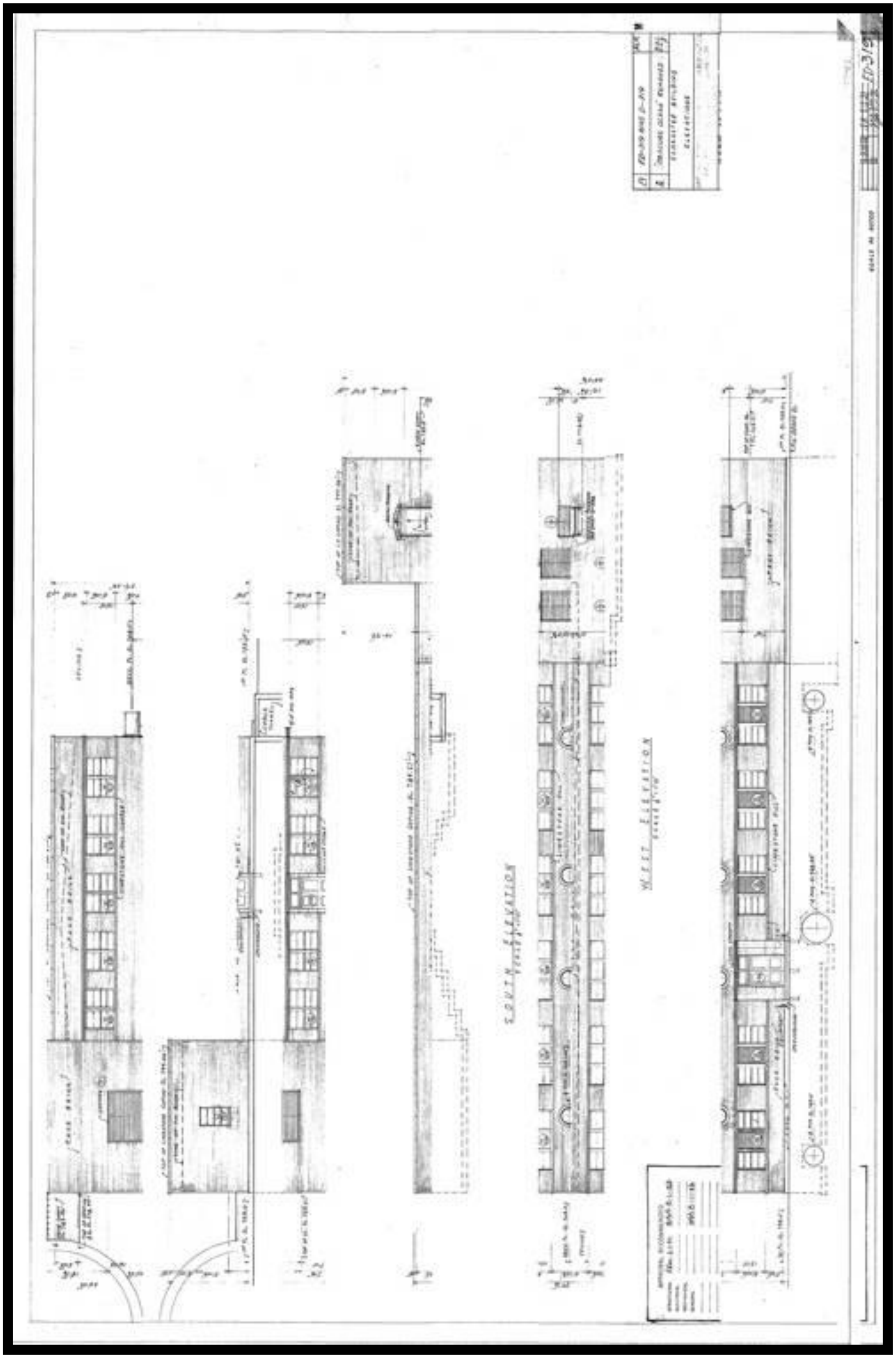
The former Exhauster Building (Building 8), now the Visitors Information Center, was a rectangular structure to the east of the Altitude Wind Tunnel (AWT). This building performed two crucial roles for the wind tunnel—it housed the drive motor that ran the tunnel's fan, and it contained the compressors that evacuated the tunnel to simulate the pressures at high altitudes.

The 91-foot 8.5-inch wide and 148-foot long Exhauster Building consisted of three sections. The main portion of the building was a two story open room that housed the exhausters. The area to the south of this was carved up into several rooms that housed large generators. Off the southwest corner of the building is a three-story 13-foot 8.5-inch square tower which housed the drive motor for the wind tunnel.

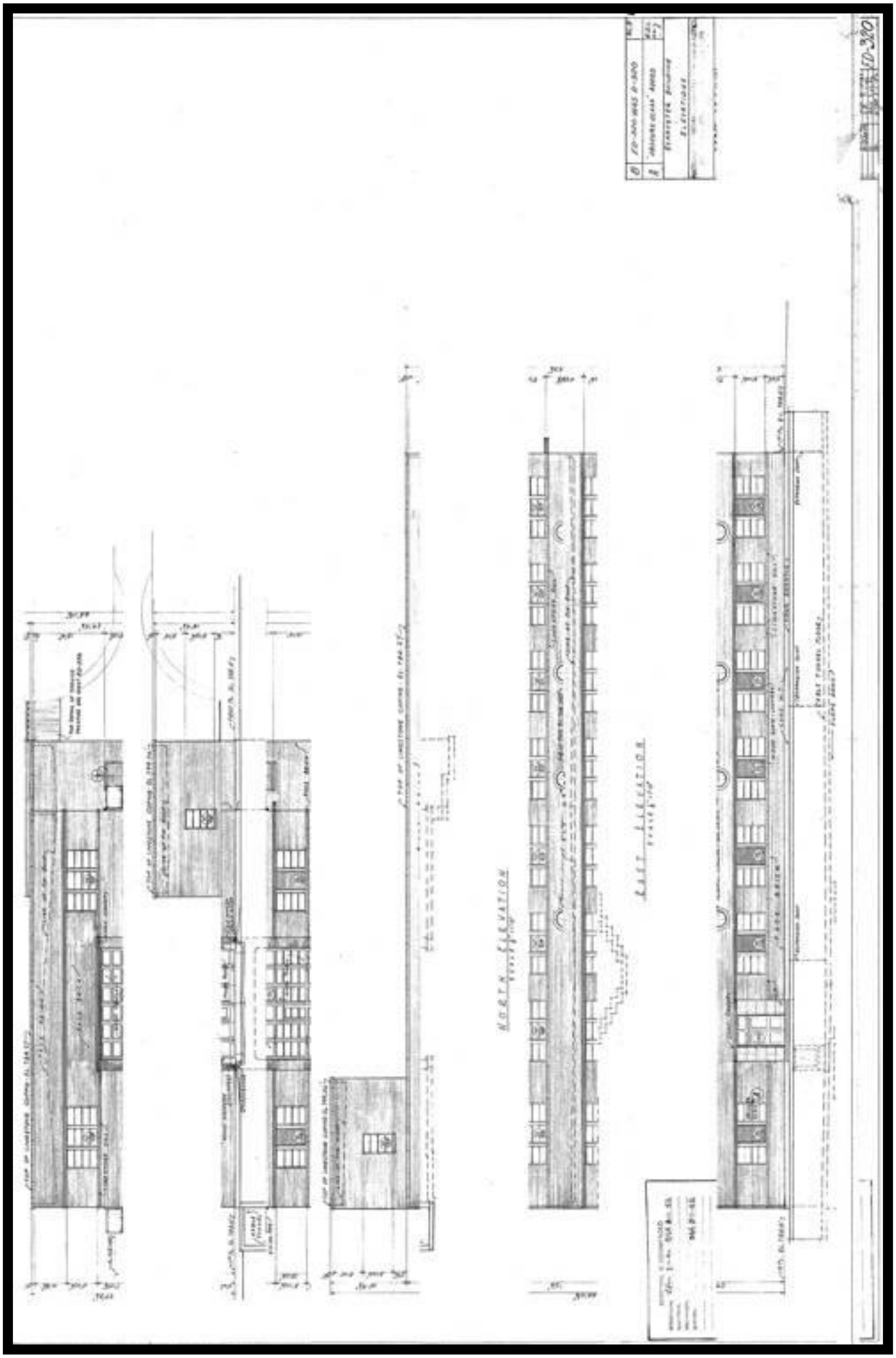
The Exhauster Building was constructed by the Sam W. Emerson Company. Roots-Connersville supervised the installation of the exhausters. The Arthur E. Magher Company assembled the exhausters after their delivery from Worthington during the summer of 1943. General Electric installed the drive motor.[363] Construction began in the summer of 1942 and was completed by September 1943.[364]



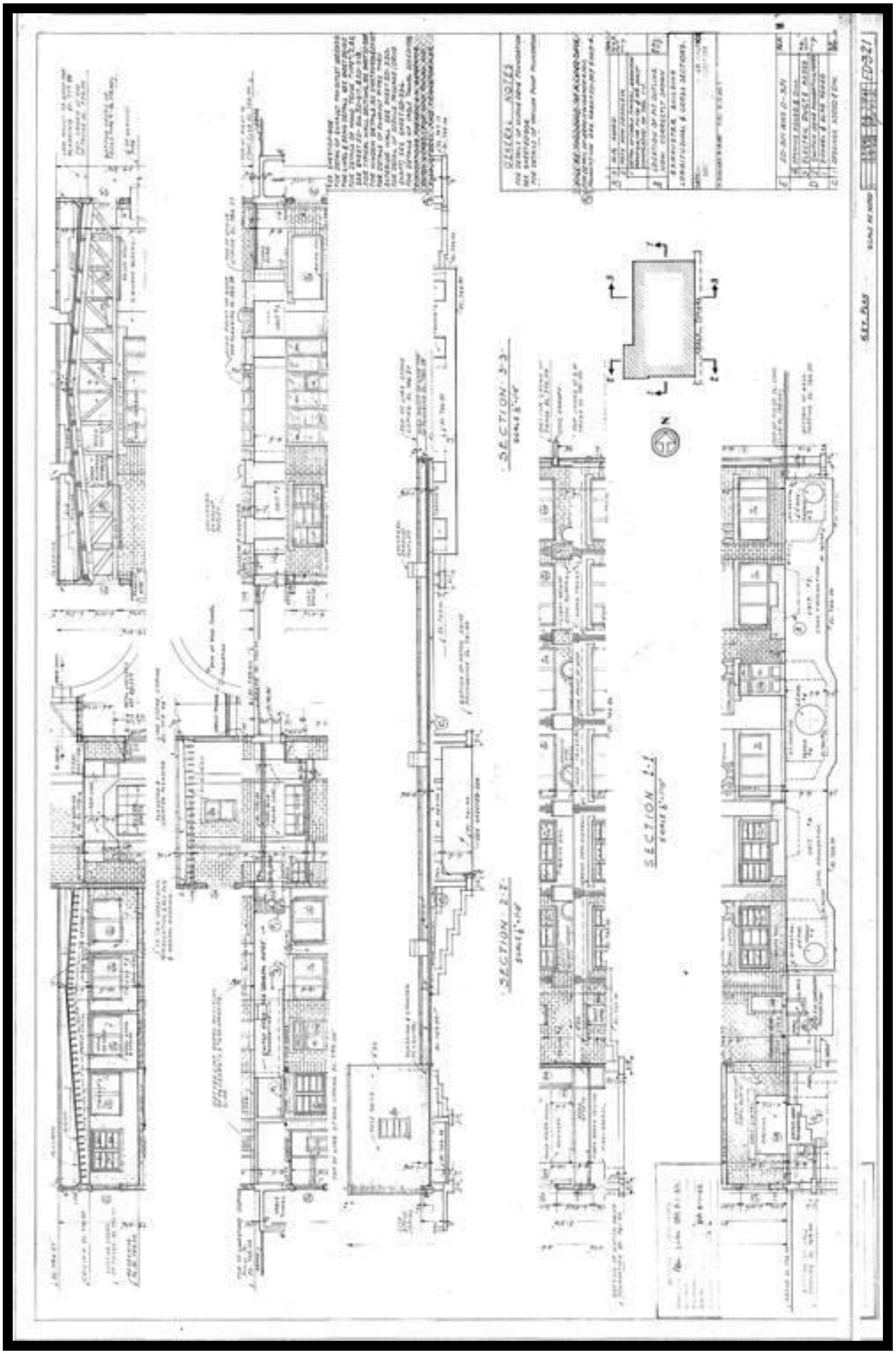
Isometric drawing of original layout of Altitude Wind Tunnel Exhauster Building
Support Image No.42: 1943-02020/NASA Glenn Research Center
(1943)



Elevation drawing of the Exhauster Building
Support Image No. 43: ED 319 01 B/NASA Glenn Research Center

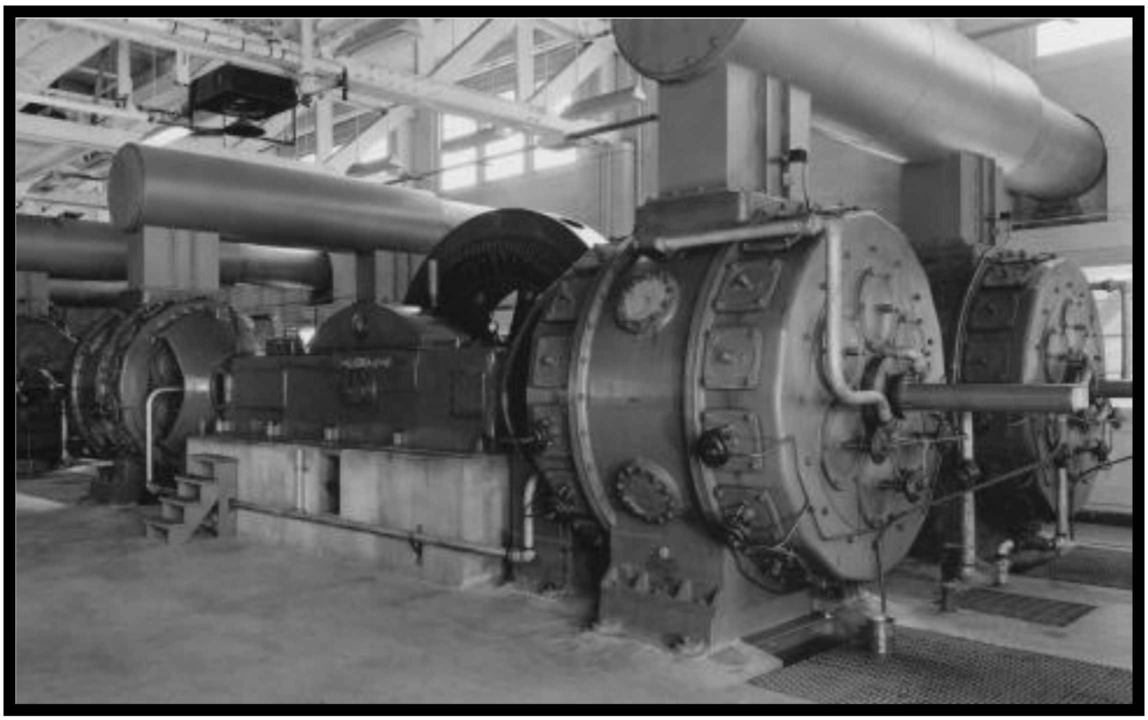


Elevation drawing of the Exhauster Building
Support Image No 44: ED 320 01 B/NASA Glenn Research Center



Elevation drawing of the Exhauster Building
Support Image No 45: ED 321 01 E/NASA Glenn Research Center

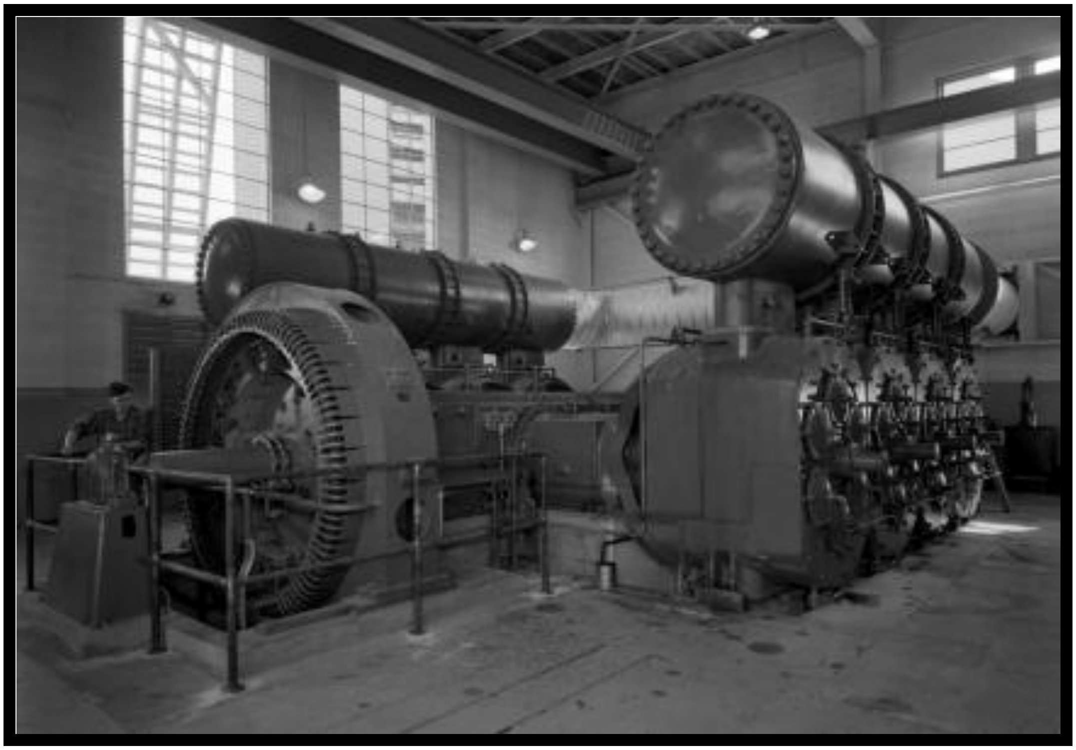
Exhausters: The main room which housed the exhausters was 29 feet 3 ¼ inches tall. A large wooden platform supported by trusses spanned rear of the room originally. The room housed four 4-cylinder 60-inch bore and 30-inch stroke Worthington reciprocating exhausters that were powered by a 1750-horsepower motor. These exhausters were tied to the air scoop inside the wind tunnel. After removing the air from the tunnel the pumps expelled it into the atmosphere through ducts in the Exhauster Building walls. Each exhauster possessed two horizontal 36-inch diameter exhaust pipes. The portal for each pipe was elevated 13 feet ½ inches from the ground and had a reinforced concrete collar and metal ring. An adjustable pipe roll stand was anchored just below the pipe to the wall.[365] Mufflers, perpendicular to the pipe and with concrete caps, were added to all eight of these pipes in 1945.[366]



One of four Worthington exhausters with its two 36- inch exhaust pipes Exhauster Building
Support Image No.46: 1944-06710/NASA Glenn Research Center (1944)

A smaller rectangular addition was attached to the northeast corner of the building in 1951. This new addition contained three eight cylinder Ingersoll-Rand reciprocating pumps.[367] The AWT exhausters were initially constructed to handle 12-pounds per second at 50,000 feet and 66-pounds per second at 28,000 feet. With the new addition the exhausters were upgraded to 7-pounds per second at 50,000 feet and 51-pounds per second at 28,000 feet.[368] An exhaust gas cooler, pump house, and cooler pit were also installed underneath the air scoop where the tunnel where it exited the east side of Building 7.[369]

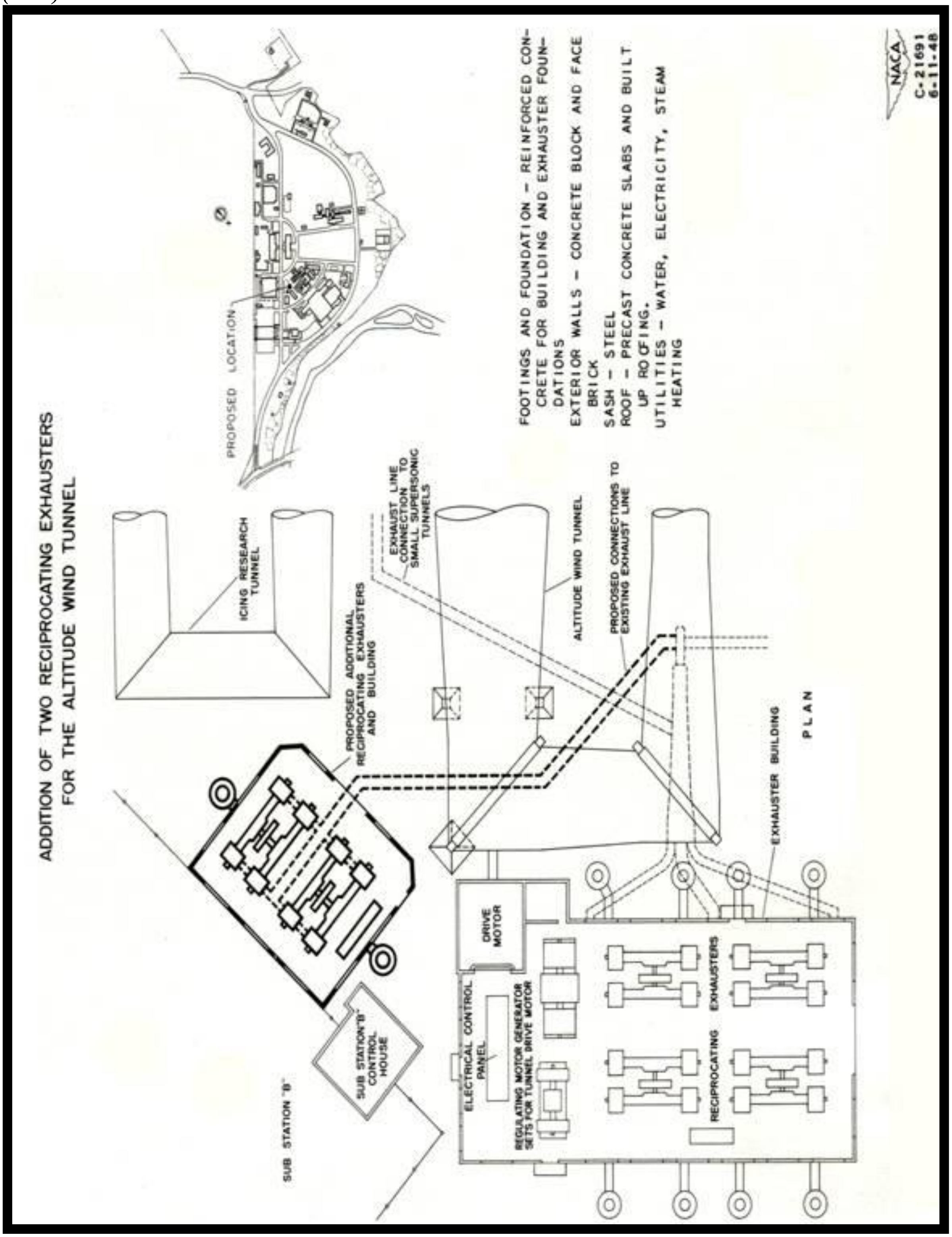
The new building was 93 feet 4 ½ inches wide, 49 feet 10 ½ inches long, and approximately 25 feet 2 inches high. The new compressors were positioned north and south and were joined together by a 48-inch diameter pipe. The new compressors were linked to the new pump house via a 36-inch diameter pipe that traveled through the original Exhauster Building.[370] The exterior was finished in identical brick scheme as the original building. It has a vertical lift door on the east end of the north side and a pedestrian doorway on the west end of the north side. There was another pedestrian entrance on the west end of the south side.[371]



Ingersoll-Rand exhausters in the 1951 addition to the Exhauster Building
Support Image No. 47: 1952-29447/NASA Glenn Research Center *(1952)*

View from north of former Exhauster Building with the 1951 addition off the northeast corner.

Support Image No.48: 2005-02577/NASA Glenn Research Center (2005)

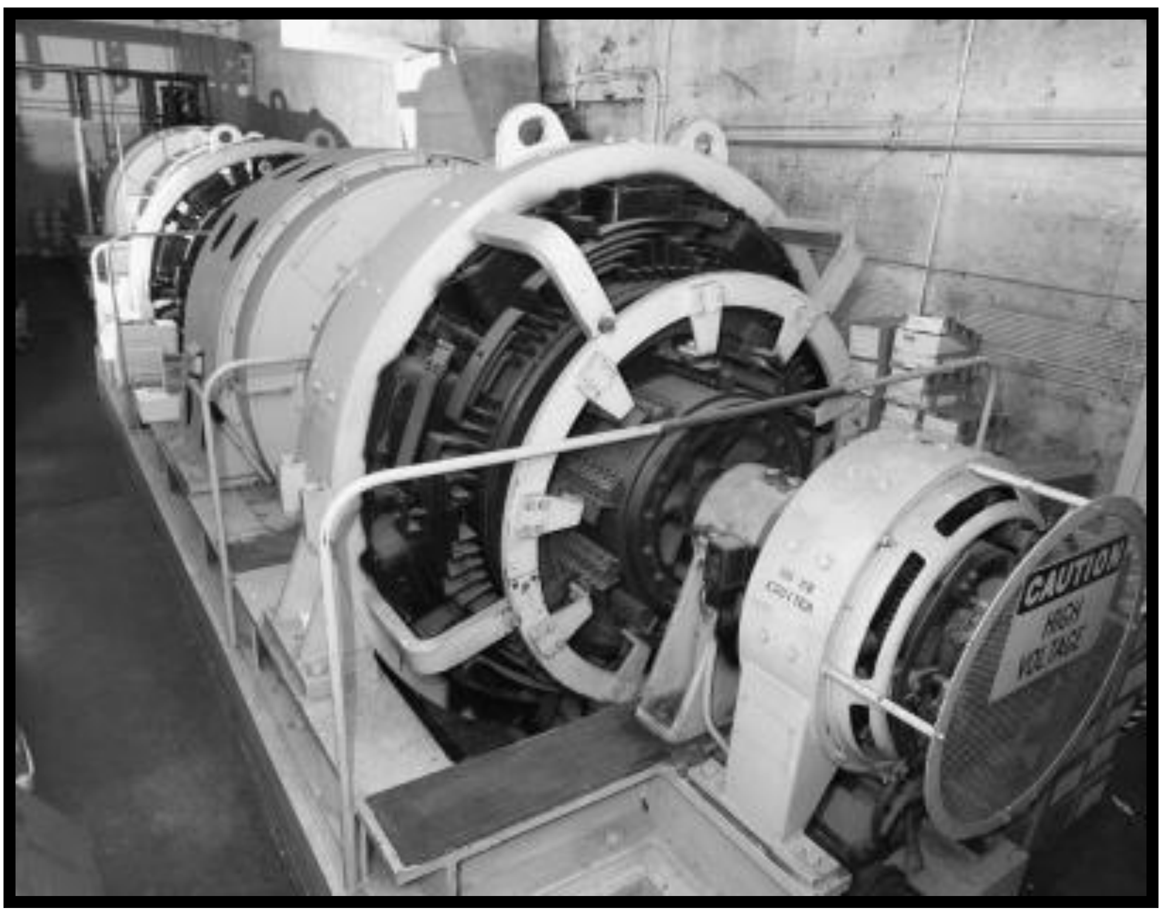


Drawing showing addition of two exhausters to Exhauster Building
Support Image No. 49: 1948-21691/NASA Glenn Research Center

The air distribution system was modified again in 1956. A new 8-foot diameter 228-foot long pipe was installed between the ERB and the AWT exhaust system.[372] In 1965, the Exhauster Building was rehabbed. The flooring was improved, obsolete hardware removed from walls, a new sound resisting ceiling installed.[373]

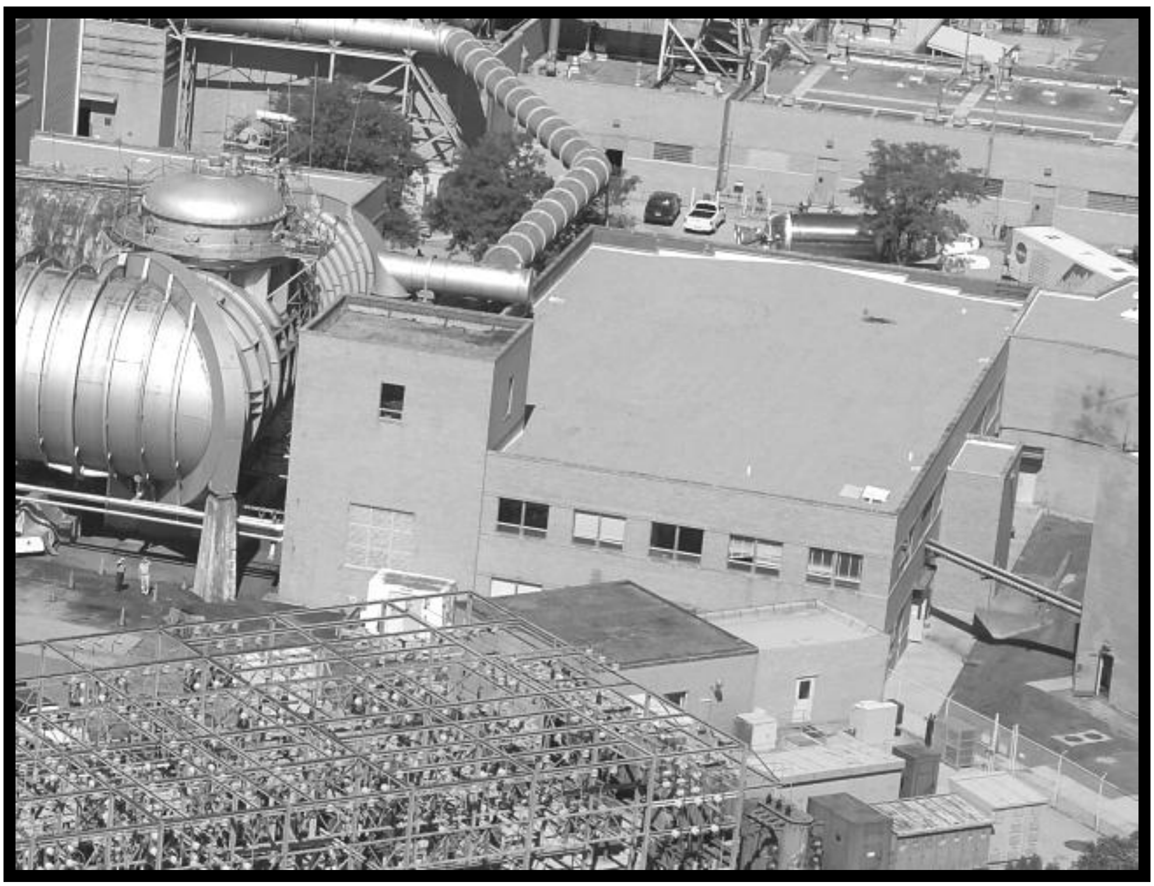
Generators: The rear portion of the Exhauster Building was 44 feet tall and consisted of two sections—a narrow open area for two power generators and a two level area for offices. The restrooms and a stairwell accessing the second floor were along the east wall behind the smaller generator. The second floor contained four small offices.[374]

This area was used as the Solar Power Laboratory in the 1960s after the generators were no longer needed to operate the wind tunnel fan. The lab's work included the rapid assembling of the components of a large Brayton Cycle Power System so that they could be tested in the Space Power Facility.[375] This room is presently used for storage of NASA educational publications.



One of two generators in the Exhauster Bldg. that were used to help power the AWT drive motor
Support Image No. 50: 2005-01684/NASA Glenn Research Center
(2005)

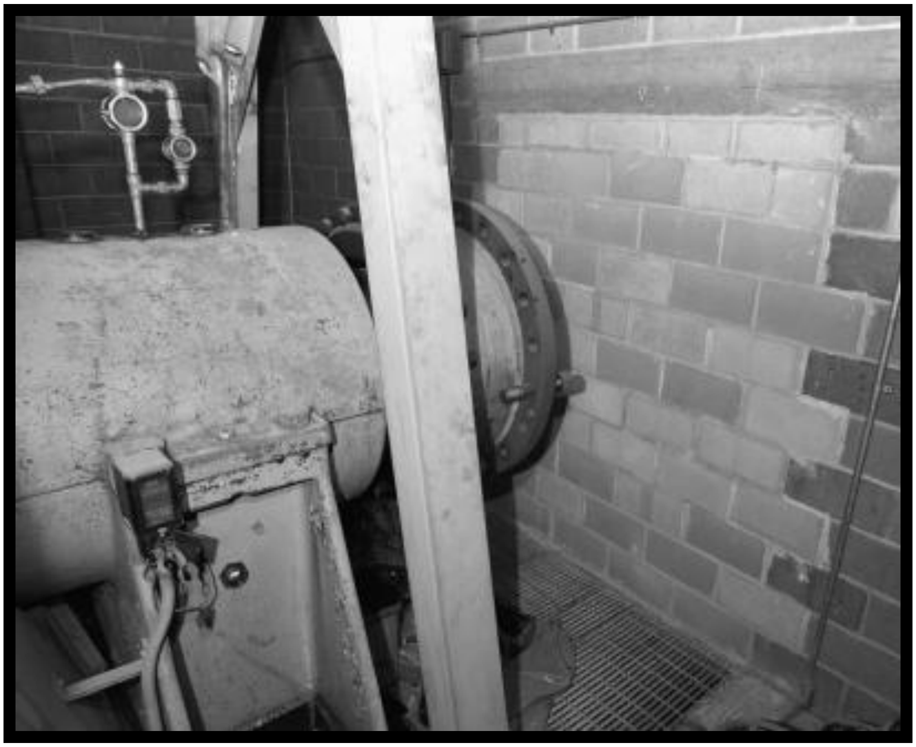
Drive Motor: The southwest corner of the Exhauster Building was built like a three-story tower. The first level housed a small generator that helped power the AWT's drive motor. The drive motor occupied the upper two levels. The drive shaft traveled from the upper level and into the tunnel shell on the east end of the facility. The tower rooms were 28 feet 6.25 inches wide and 23 feet 3 inches deep. These were accessible via an iron ladder in the northeast corner of the rooms.[376] The second level of the tower is 8 feet 6 inches above the first floor. The third level is another 16 feet 11 inches further. The second floor area contained a secondary motor and fan which exhausted through a 6 foot 2 ½ inch metal duct in the west wall. [377]



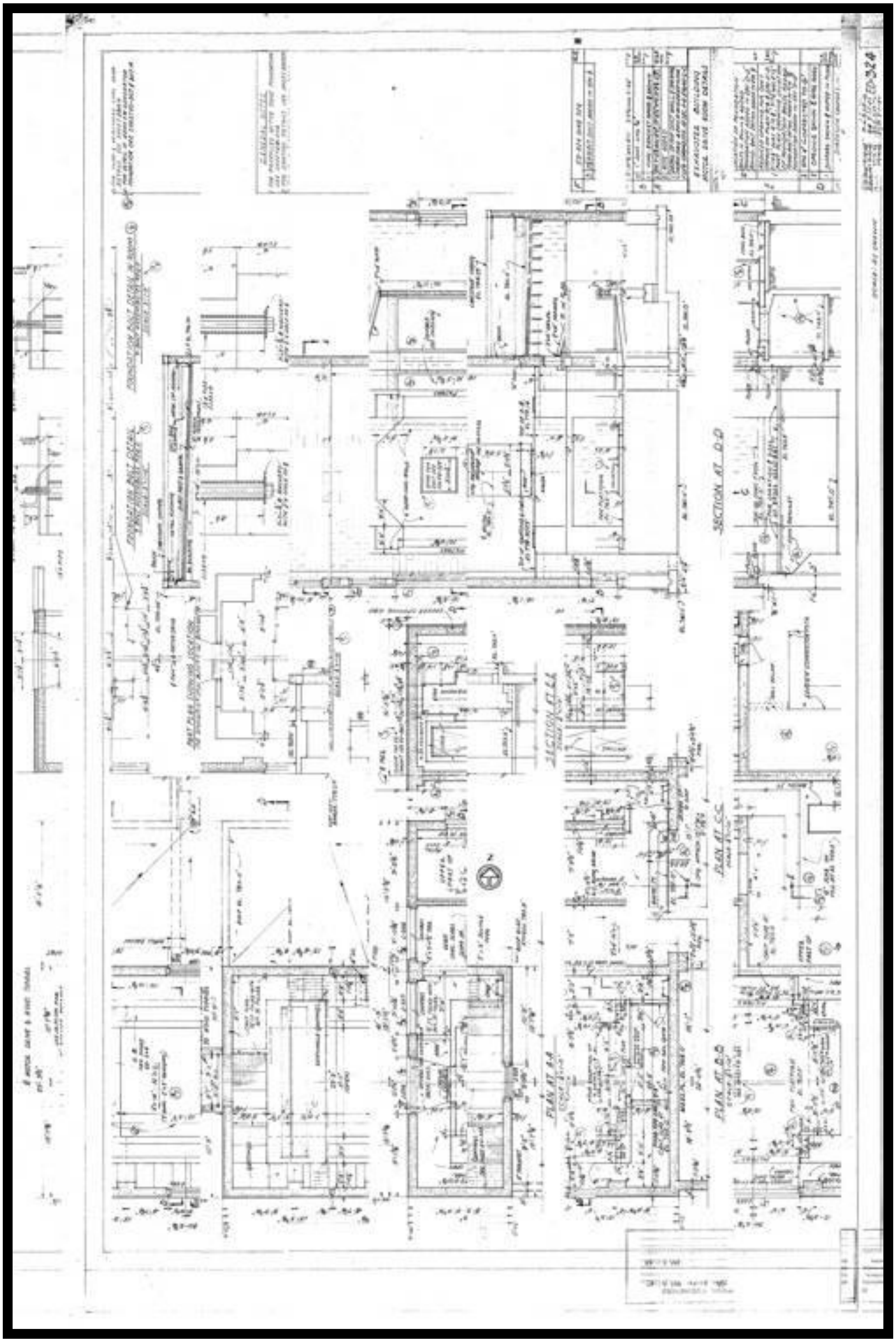
View from south of drive motor tower in rear of the Exhauster Building.
Support Image No. 51: 2007-02576/NASA Glenn Research Center (2005)

The primary drive motor was an 1800-horsepower, 4000-volt, 2180-amp General Electric induction motor. It sat on steel plates on the 6-inch thick concrete base in the third level. There is another concrete slab along the north wall, but the remainder of the room's flooring consists steel grating. The room had a 3 foot 9 ½ inch wide window on the north, south, and east walls. [378] It was 16 feet 3 inches wide at its base. The circular drive motor extended below the floor level and supported by a concrete partition. The drive shaft rested on bases on either side of the motor.[379] The drive shaft traveled approximately 8 feet 4 inches between the exterior wall and the wind tunnel wall.[380] The drive shaft was elevated approximately 28 feet and 6 inches from the ground.[381]

View facing southwest of the General Electric induction motor that was used to drive the AWT fan.
Support Image No. 52: 2005-01676/NASA Glenn Research Center (2005)



View of drive shaft that formerly exited this western wall of the Exhauster Bldg. to rotate the AWT fan
Support Image No. 53: 2005-01683/NASA Glenn Research Center (2005)



Drawing of motor drive room in Exhauster Building
Support Image No. 54: ED 324 01 F/NASA Glenn Research Center

Visitors Information Center: In the mid-1960s the large exhausters were removed from the Exhauster Building, and it was converted into the Solar Power Laboratory. In July 1970, however, the structure opened as the Aerospace Information Display (AID) building. The AID contained NASA models, hardware, and exhibits, including large scale models of an Apollo capsule, the Lunar Module, and all of NASA's launch vehicles.

In 1975, the AID was expanded and renamed the Visitors Information Center (VIC). A large lobby area was created at the nexus of the original Exhauster Building and the 1951 annex. The large exhauster room is filled with displays, an electronics shop, and restrooms.[382] The annex became a 170 seat assembly room with a stage along the east wall. It also included an office and coat room. The second level, which does not cover the building's entire footprint, is used as offices for the Community and Media Relations Office and the Educational Programs Office. Its basement is used as storage for the Visitor Center's audio/visuals and educational displays. [383]

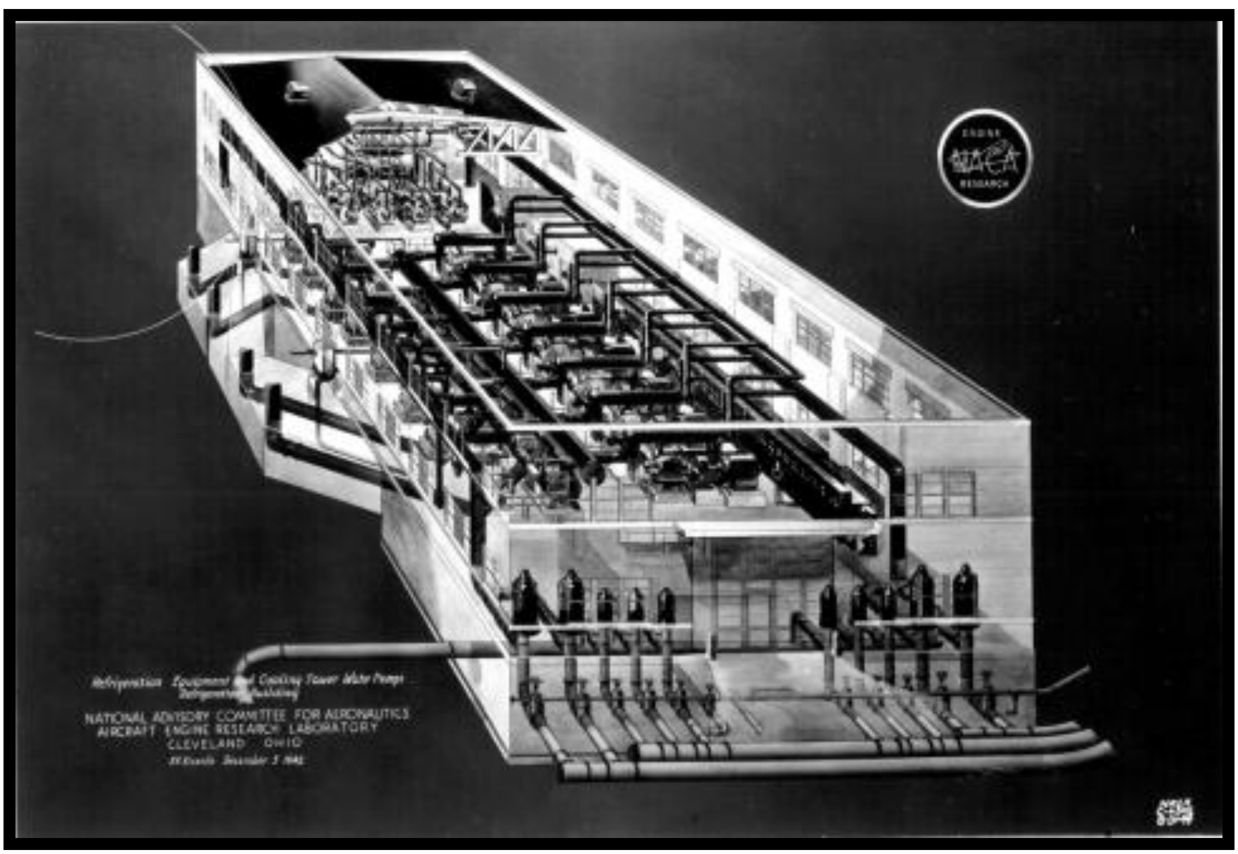
Aerospace Information Display in the former Exhauster Building
Support Image No. 55: 1970-02258/NASA Glenn Research Center (1970)

C. Refrigeration Building:

The Carrier Corporation-designed refrigeration system was one of the Altitude Wind Tunnel's (AWT) most vital and complex components. It could reduce the tunnel's temperature to -47° degrees F. In addition, it cooled the AWT's make-up air and fuel supply, as well as the Icing Research Tunnel and the center's chill water. According to a 1944 *Aero Digest* article, "if used for ice-making, (the system) would manufacture ten thousand tons of ice each 24 hours."[384]

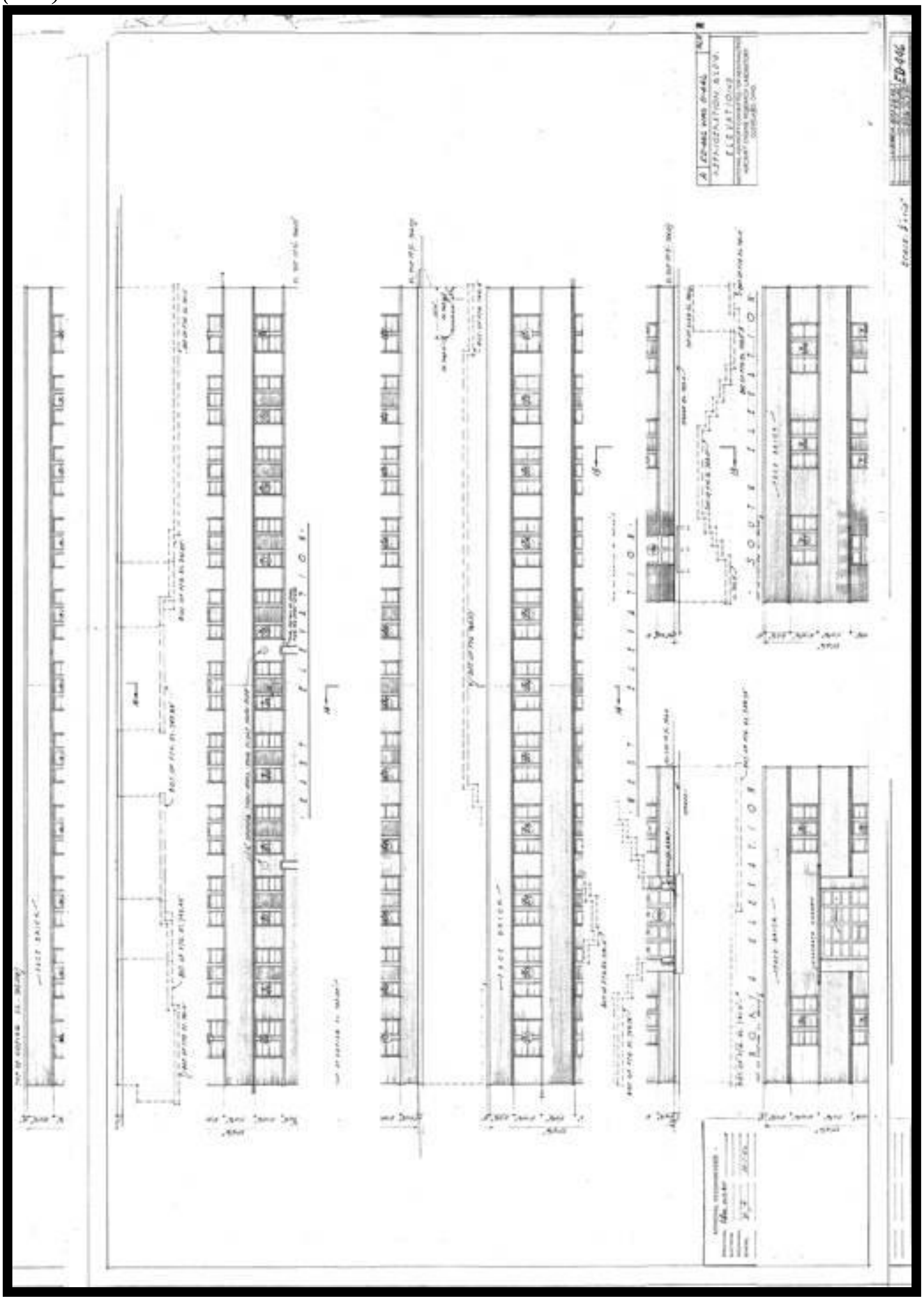
The Refrigeration Building contained the 14 Carrier compressors and flash cooler which powered the cooling system. It is a rectangular two story brick structure was constructed in the same fashion as the Shop and Office Building. The building has a truck entrance in the center of the north face and pedestrian entrances on the south and east walls. An additional pedestrian entrance was installed on the north wall. Originally the building contained two rows of sash windows along each wall. The second story level windows were later bricked over and the lower level windows were modernized.

The interior of the building is largely open with an excavated basement. There is a small control room along the western wall. The compressors are aligned in pairs facing east and west with the flash cooler running north and south between them. Several generators facing north are aligned near the rear of the building. There are two stairways leading to the basement, one near the control room, and the other near the front of the building.



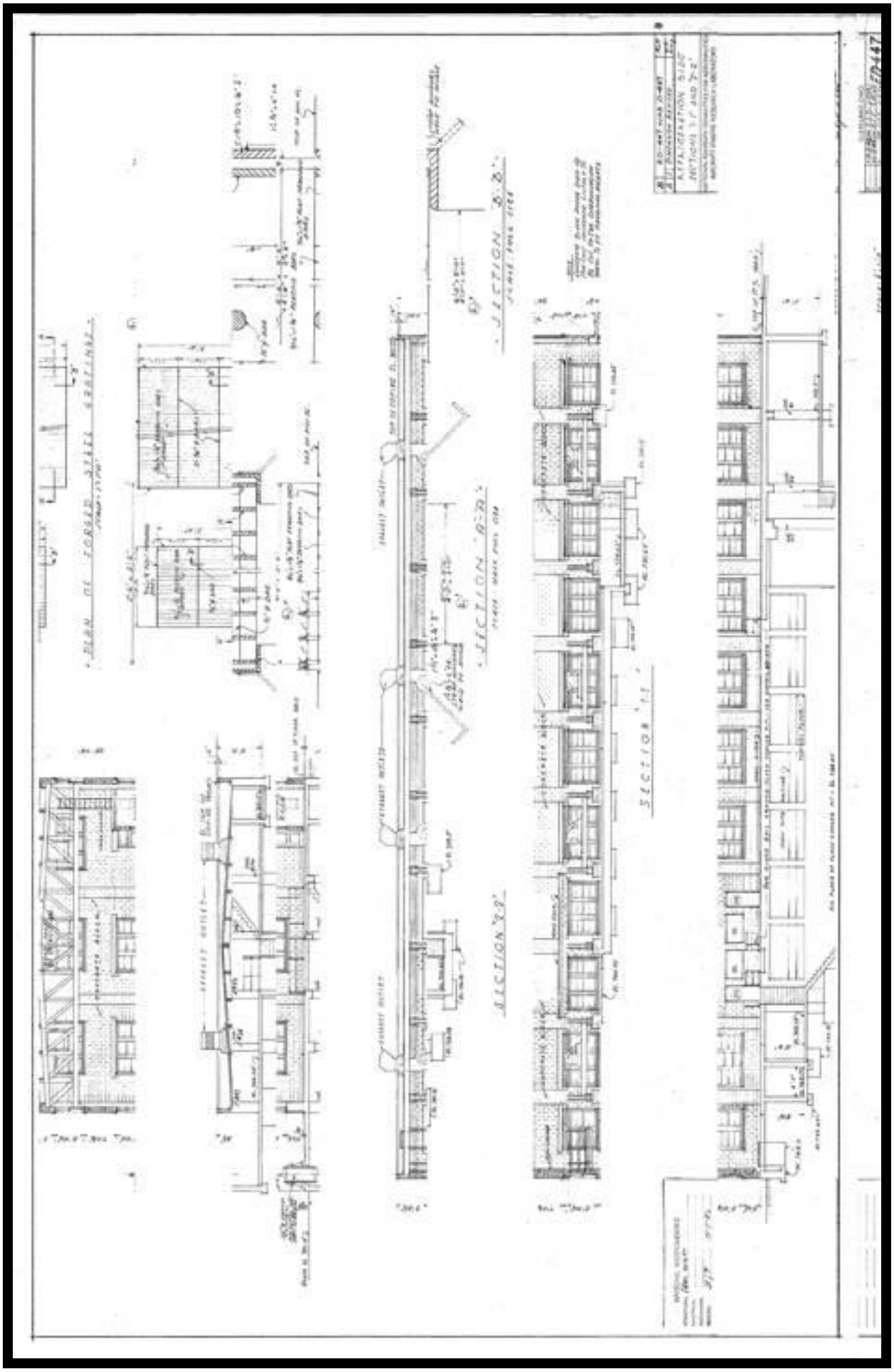
Isometric drawing of the Refrigeration Building which housed the cooling system for AWT and the Icing Tunnel

Support Image No.56: 1944-6304/NASA Glenn Research Center (1944)

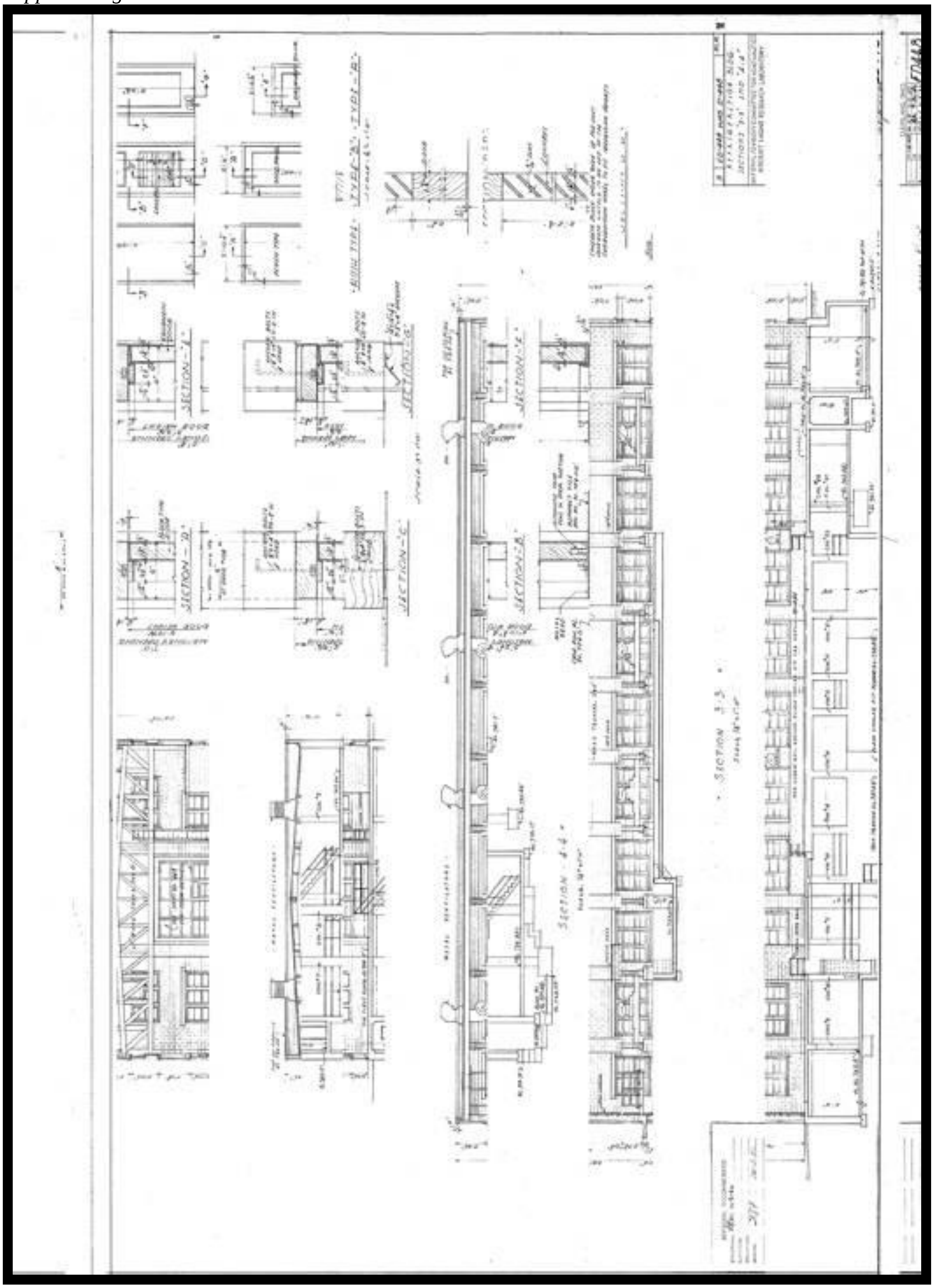


Elevation drawing of the Refrigeration Building

Support Image 57: ED 446 01 A/NASA Glenn Research Center



Sections and Cross-sections of the Refrigeration Building
Support Image No. 058: ED 447 01 B/NASA Glenn Research Center



Drawing of sections of the Refrigeration Building
Support Image 059: ED 448 01 A/NASA Glenn Research Center

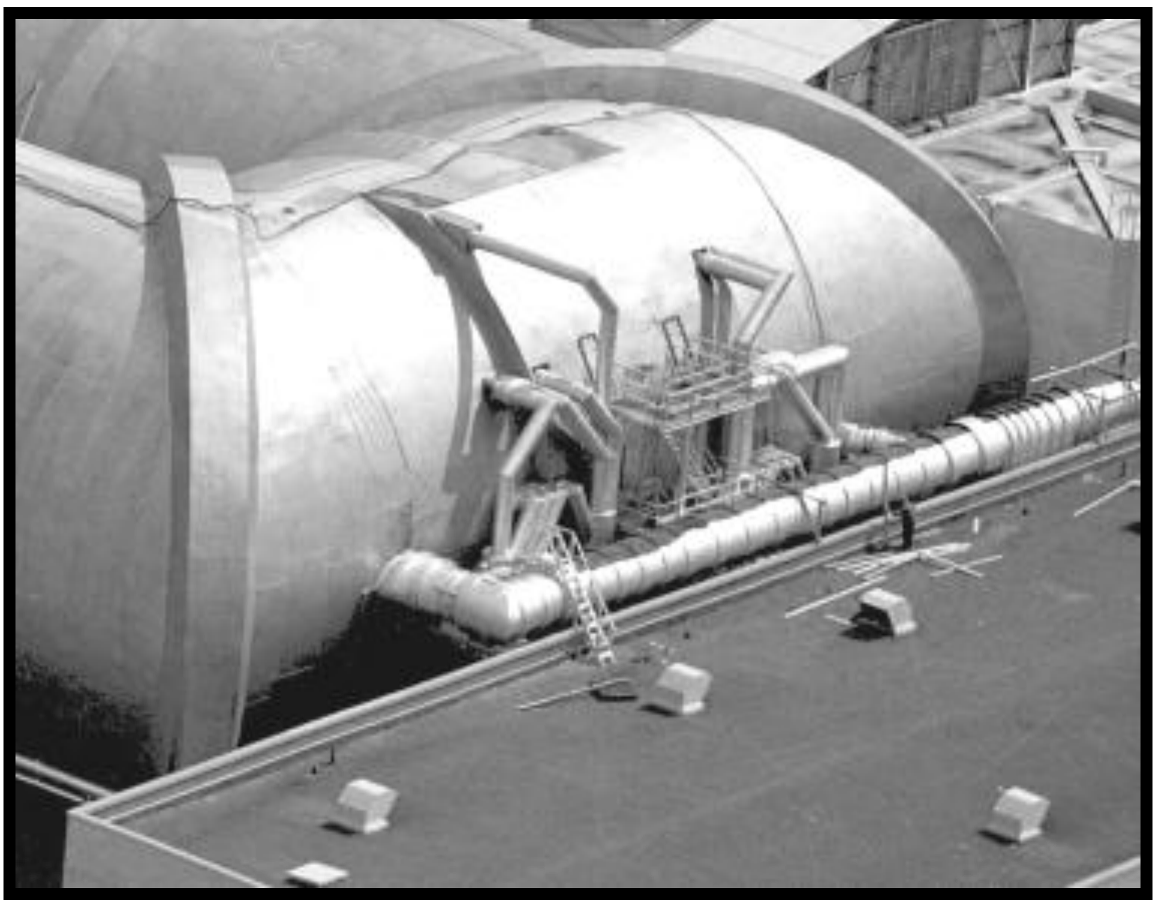
Cooling System: The Carrier Corporation, based in Buffalo, New York, designed and constructed the refrigeration system. Originally the NACA engineers wanted to use a new untried cooling coil with streamlined tubes. Willis Carrier convinced the agency that his coils were superior and the task was turned over to his company.[385] A scale model of the tunnel was built in 1942 at the Carrier plant so that their engineers could find a way to optimize the distribution of the refrigeration.[386] The Pittsburgh-Des Moines Steel Company installed the refrigeration system, which included external coils and headers, liquid and vapor lines, expansion joints, and an exhauster trench.[387] Installation of the Flash Cooler began in mid-June 1943 and the entire building was completed in the fall of 1943. [388] Between the Refrigeration Building and the tunnel, approximately 30 different lines from the heat exchangers condensed into the four return pipes.

The fourteen 1500-horsepower Carrier centrifugal compressors and a flash cooler were modified to use Freon 12 refrigerant. Originally the compressors changed the temperature of the Freon 12 by 20,000 feet which equals 150° F. This was accomplished by taking in a volume of gas through a four-stage compressor, then releasing the superheated and compressed gas into the condenser. The condenser takes water from the cooling tower to cool its tubes while the superheated gas from the compressor is passed around the four tubes.[389] The circulating water removed the heat from the refrigeration equipment to the cooling tower where it was dissipated into the atmosphere. At its original capacity, 20,000 gallons of cooling water were required every minute.[390]

The flash cooler is prepared for installation in the Refrigeration Building in July 1943
Support Image No. 60: 1943-01916/NASA Glenn Research Center (1943)

The two-stage cooler sub-cooled the condensed refrigerant as it passed from the condenser to the cooler. This process reduces the pressure and temperature to the pressure of the third-stage suction pressure and the remaining refrigerant is evaporated. The horsepower-per-ton of refrigeration was substantially economized. The refrigerant was then pushed to the flash cooler where the suction gas was separated and the refrigerant was injected with hot gas. The refrigerant is sub-cooled in the flash cooler before the liquor pumps propel it through the evaporator. The tunnel's heat is also absorbed by the latent heat contained in excess refrigerant.[391]

The dampers, which were regulated by thermostats, controlled the refrigeration system's weight flow and thus power. Heat exchangers in the tunnel's western leg were used to create the low temperatures found at higher altitudes. The AWT and IRT were cooled using almost identical heat exchangers. In an effort to maintain uniform temperature and frosting across the tunnel, 8 identical heat exchangers 4 tubes deep.[392]



View from northwest of lines from the Refrigeration Building entering the west wall of the AWT
Support Image No. 61: 1945-13054/NASA Glenn Research Center
(1945)

The heat exchangers were a collection of 260 copper-plated coils arranged in a zig-zag design that covered almost the entire 51-foot cross-section of the tunnel. The traditional cooling coil configuration, if used to cool such large volume of air, would not fit into the tunnel. The zig-zag layout, however, created an area of air flow through the coils approximately 4 times that of the tunnel cross section.[393]

Accordion-shaped banks of cooling coils inside the AWT.
Support Image No.62: 1950-25465/NASA Glenn Research Center (1950)

During the cooling cycle a series of valves distributes the refrigeration uniformly across the tunnel. Frost is created and friction is caused by the coils. The heat exchanger vacuum was sustained during the defrosting cycle by valves located in external two float tanks. Two liquor pumps circulated the refrigerant from the flash cooler to the heat exchanger. The refrigerant gas was converted into liquor by compressors.[394] A purge recovery system evacuates any non-condensable gases, water, and air from the refrigeration system and gathers refrigeration mixed with the air. This results in ultimate efficiency and a clean refrigeration system.[395]

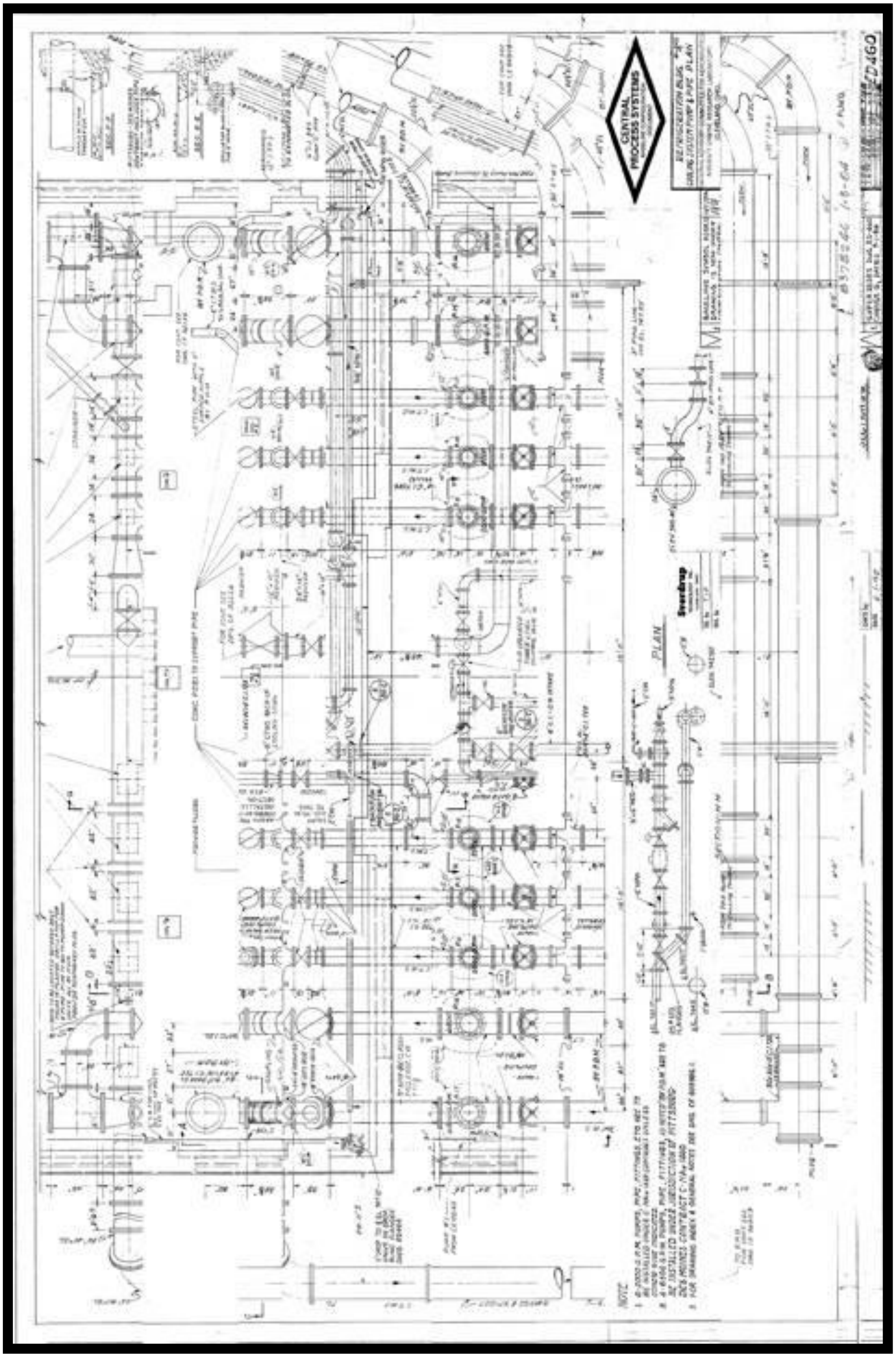
There are three 1500-horsepower York compressors that were used to chill the cooling coils in the Air Dryer Building. These compressors also supply chill water for several nearby buildings including the Engine Research Building and Administration Building. A natural gas compressor was installed for research in the Engine Components Research Lab. Five horizontal pumps and ten vertiline pumps distribute water from Cooling Tower No.1

to Buildings 5, 8, 9, 11, 77, and 98. [396] The Refrigeration Building continues to provide cooling for the Icing Research Tunnel.

View facing north of flash cooler and Carrier compressors inside the Refrigeration Building
Support Image No.63: 1951-27262/NASA Glenn Research Center
(1951)

View from north of the Refrigeration Building with the AWT to the left in the background

Support Image No.64: 2005-01634/NASA Glenn Research Center (2005)



Drawing of piping and sumps for Circulating Water Pump House
Support Image No. 65: ED 460 01 X/NASA Glenn Research Center

D. Circulating Water Pump House:

As part of the 1951 modernization project for the Altitude Wind Tunnel (AWT), a pump house was built underneath the northeast leg of the tunnel. The 54-foot 7.5-inch long and 28-foot 1.5-inch wide building ran in a diagonal southwest direction from the northeast portion of the tunnel near the exhaust scoop. The pump house contained four Ingersoll Rand pumps, two 250-horsepower discharge pumps to south, and two 300-horsepower spray pumps. Another 75-horsepower spray pump was located in northeast corner.[397] These pumps drew water from Cooling Tower No. 1 through two 24-inch and one 16-diameter underground lines that ran from the cooling tower and through the Refrigeration Building.[398]

A large cylindrical cooler pit was installed underneath the exhaust scoop in the northeast leg of the tunnel. This cooler was connected to the new pump house. The tunnel's air scoop funneled the contaminated air out the bottom of the tunnel and through this 10-foot long and cooler. [399] A 72-inch diameter exhaust pipe extended from the back of the cooler. It traveled vertically approximately 26 feet including an expansion joint before splitting. One pipe turned horizontally through the Exhauster Building and into the new addition.[400] The other ran north across Ames Road and connected with the Engine Research Building's exhaust system.[401]

View from west of former Circulating Water Pump House beneath the Altitude Wind Tunnel

Support Image No. 66: 2007-00405/NASA Glenn Research Center (2007)

Three of four sump pumps inside the Circulating Water Pump House during its construction in 1951

Support Image No 67: 2007-02591/NASA Glenn Research Center (1951)

Installation of the exhaust gas cooler under northeast tunnel section during the upgrade of the AWT

Support Image No. 68: mod-awt-c-10/NASA Glenn Research Center (1951)

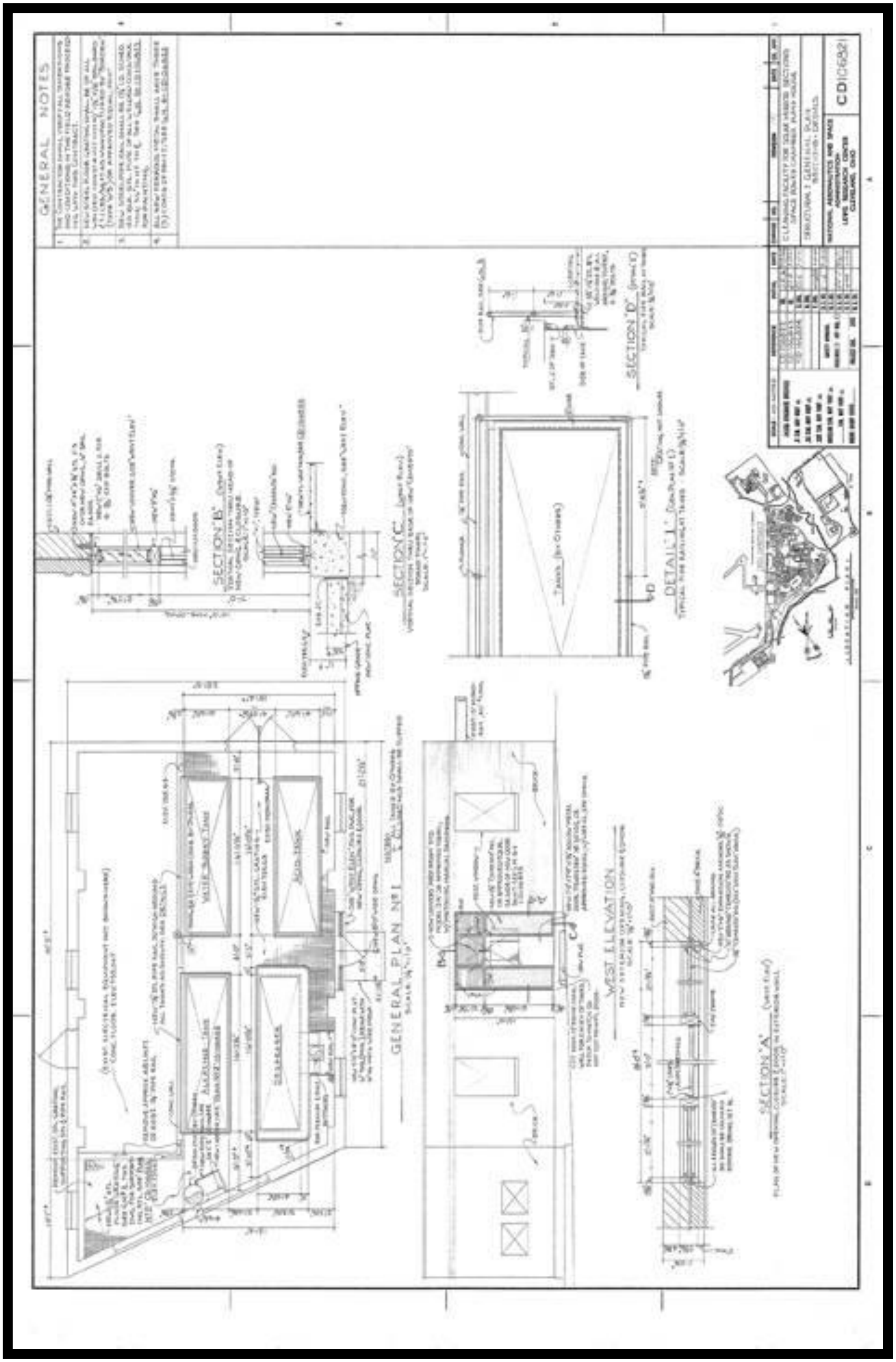
72-inch diameter pipe connecting cooler pit to Exhauster Building & Engine Research Bldg.
Support Image No.69: 2005-01473/NASA Glenn Research Center (2005)

During the 1960s, this structure was renamed the Solar Power Laboratory Annex and used by the Technical Services Division' Refrigeration Section for storage and as a shop and tool crib area. The Solar Power Laboratory was located nearby in the southwest corner of the Exhauster Building.[402] In recent years the pump house building was used for storage by the Educational Services Division. The structure was demolished in 2009 as part of the AWT demolition.

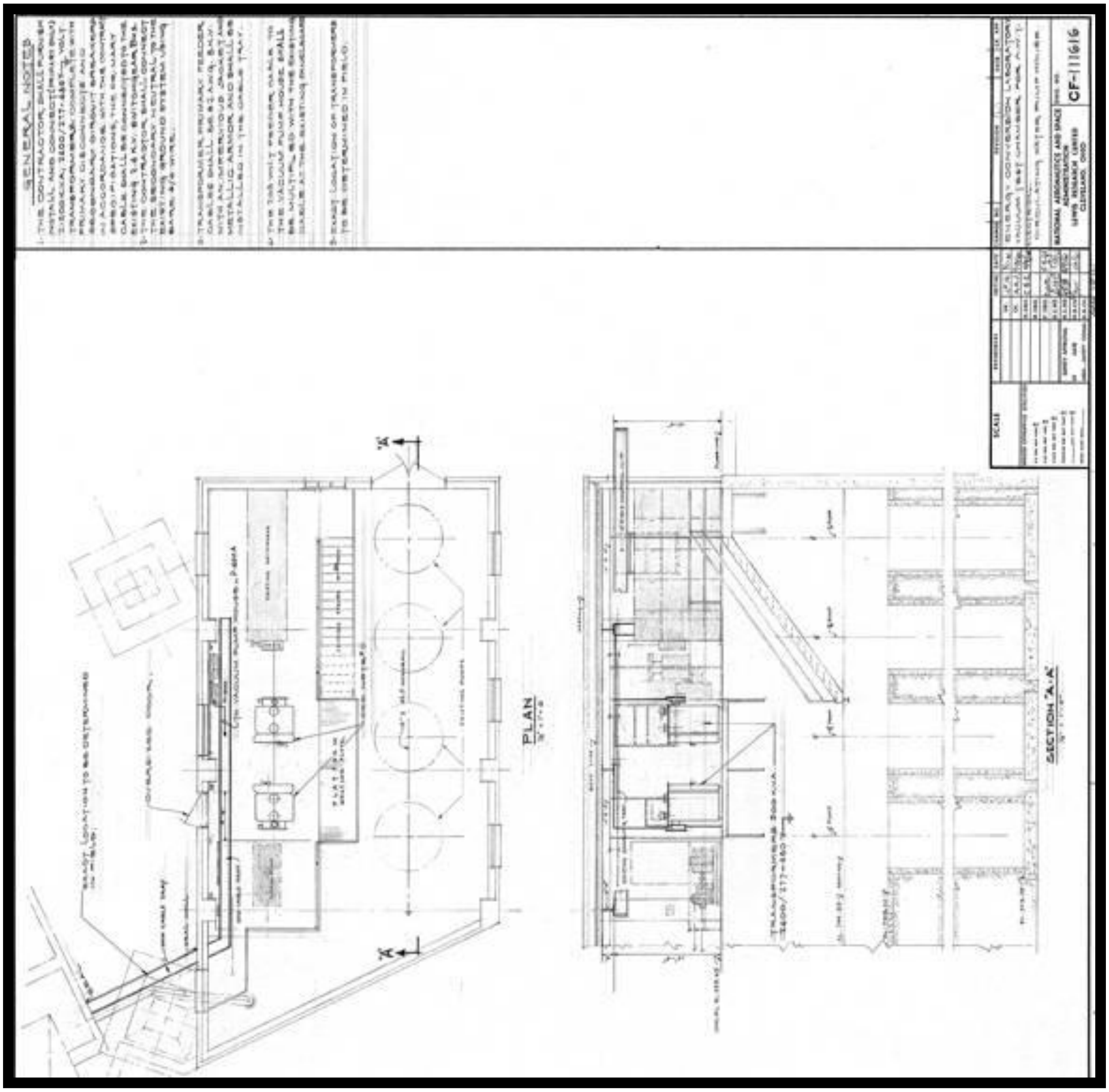
View from west of cooler pit area under northeast portion of the tunnel
Support Image No.70: 2007-00404/NASA Glenn Research Center (2007)

View from west of the former Circulating Water Pump House

Support Image No. 71: 2007-00412/NASA Glenn Research Center (2007)



Drawing of cleaning section for solar power mirrors in old pump house
Support Image No. 72: CD 106821/NASA Glenn Research Center



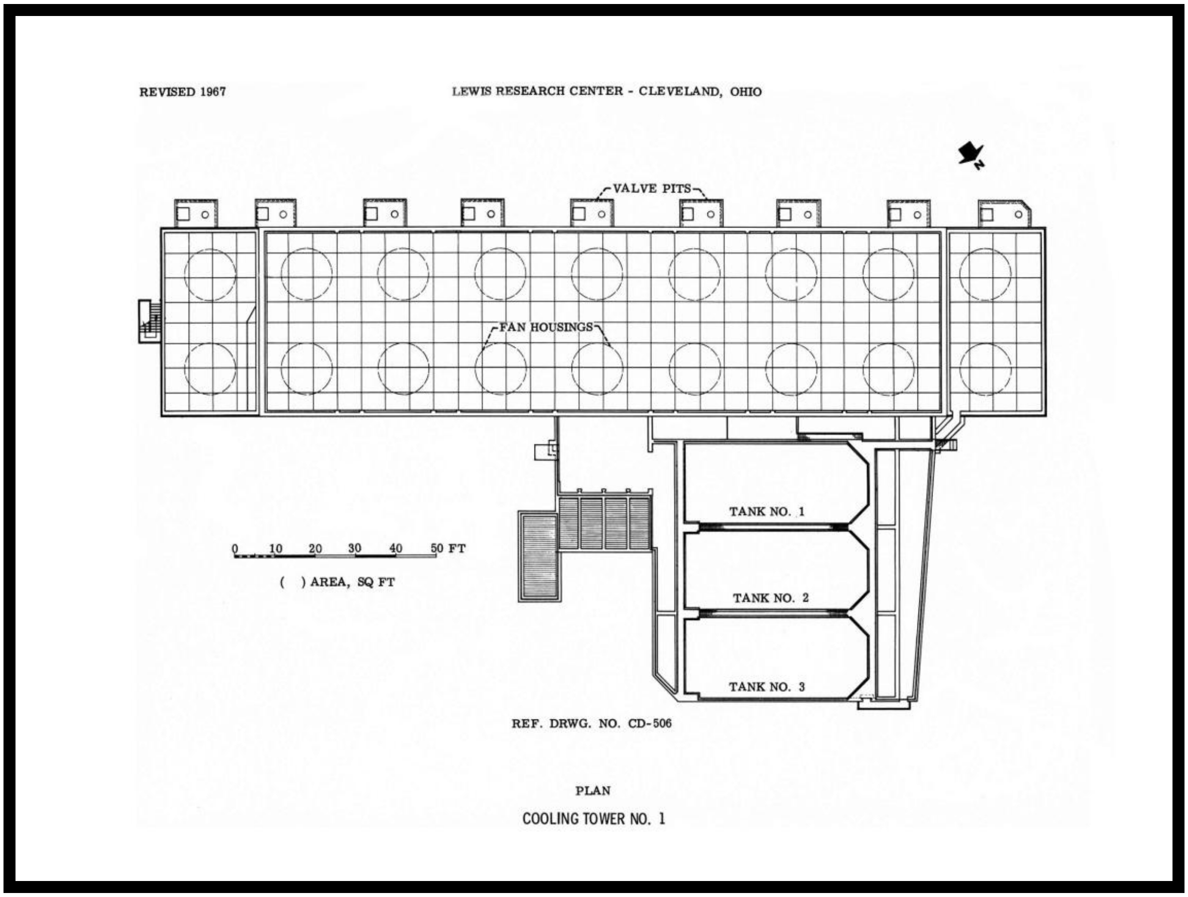
Elevation drawing for the Circulating Water Pump House
Support Image No. 73: CF 111616 01/NASA Glenn Research Center

E. Cooling Tower No.1:

Cooling Tower No.1 sits behind the Refrigeration Building diagonally in a northwest direction along Moffett Road. It is a narrow rectangular structure with a square settling basin off the northeast side. Cooling Tower No.1 originally had 8 pairs of fans in its roof to push the water spray down into the 600,000 gallon basin at the bottom of the tower. In the mid-1950s it could pump 63,000 gallons per minute.[403]

Five underground lines run northward from the tower before forming right angles toward the Icing Research Tunnel. Two lines, ranging from 6 to 18 inches in diameter, exit each of the larger lines and enter the north wall of the Refrigeration Building. These lines exited the Refrigeration Building and connected to the Circulating Water Pump House through two 24-inch and one 16-inch diameter lines.[404] Two other lines, 24 and 30 inches in diameter exit the south side of the cooling tower and wrap around and connect to the Engine Research Building.[405]

In 1951, an additional cell was added to each end of the tower resulting in 4 new fans. There is an auxiliary water basin in the center off the north side and large tank area to the west of this basin contains three tanks. Over several years all of the cells were rehabbed. And in the mid-1980s, the facility was largely rebuilt.[406] It is still used in conjunction with the Refrigeration Building by the Icing Research Tunnel.



Support Image No.74: Cooling Tower No.1 Plan, Revised 1967/ NASA Glenn Research Center

View from southwest of Cooling Tower No.1.
Support Image No.75: 2005-01637/NASA Glenn Research Center *(2005)*

View from northwest of Cooling Tower No.1 with its settling basins in the foreground
Support Image No.76: 2005-01635/NASA Glenn Research Center *(2005)*

F. Air Dryer Building:

The Make-up Air System was designed to replenish the air in the Altitude Wind Tunnel (AWT) that was removed by the exhaust scoop. The Air Dryer Building, located externally outside the tunnel's southwest corner, removed condensation and cooled the air to prevent shocks to the airflow as it entered the tunnel. The facility consisted of the air dryer tank and two sets of cooling coils. The approximately 28-foot 8-inches diameter tank was enclosed in a two-story brick building with cooling coils located before and after. It was connected in front and behind by large ducts to the primary and secondary coils buildings. The Primary Coils Building was 21 feet 3.5 inches wide and 25.25 inches long. The Secondary Coils Building was 24 feet 8 inches wide and 33 feet 8 inches long.[407]

View from west of original air dryer set up with primary coils (r), dryer tank (c), and secondary coils (l).
Support Image No.77: 1945-12004/NASA Glenn Research Center (1945)

Ambient air entered the Primary Coils Building from the south, and passed through a damper, a bank of filters, the two cooling coils, an eliminator, and another damper which reduced its temperature to about 40°F.[408] The air then entered the dryer tank where 4 flat beds of activated alumina layered on top of one another absorbed moisture to a dew point of -70°F.[409] The air then entered the Secondary Cooling Building north of the dryer which cooled the air to the desired tunnel temperature of approximately -47° F. The dryer's cooling coils were cooled by 12 reciprocating York compressors located in the nearby

Refrigeration Building. A large duct permitted air flow between the air dryer and the primary coils during cooling and activation.[410]

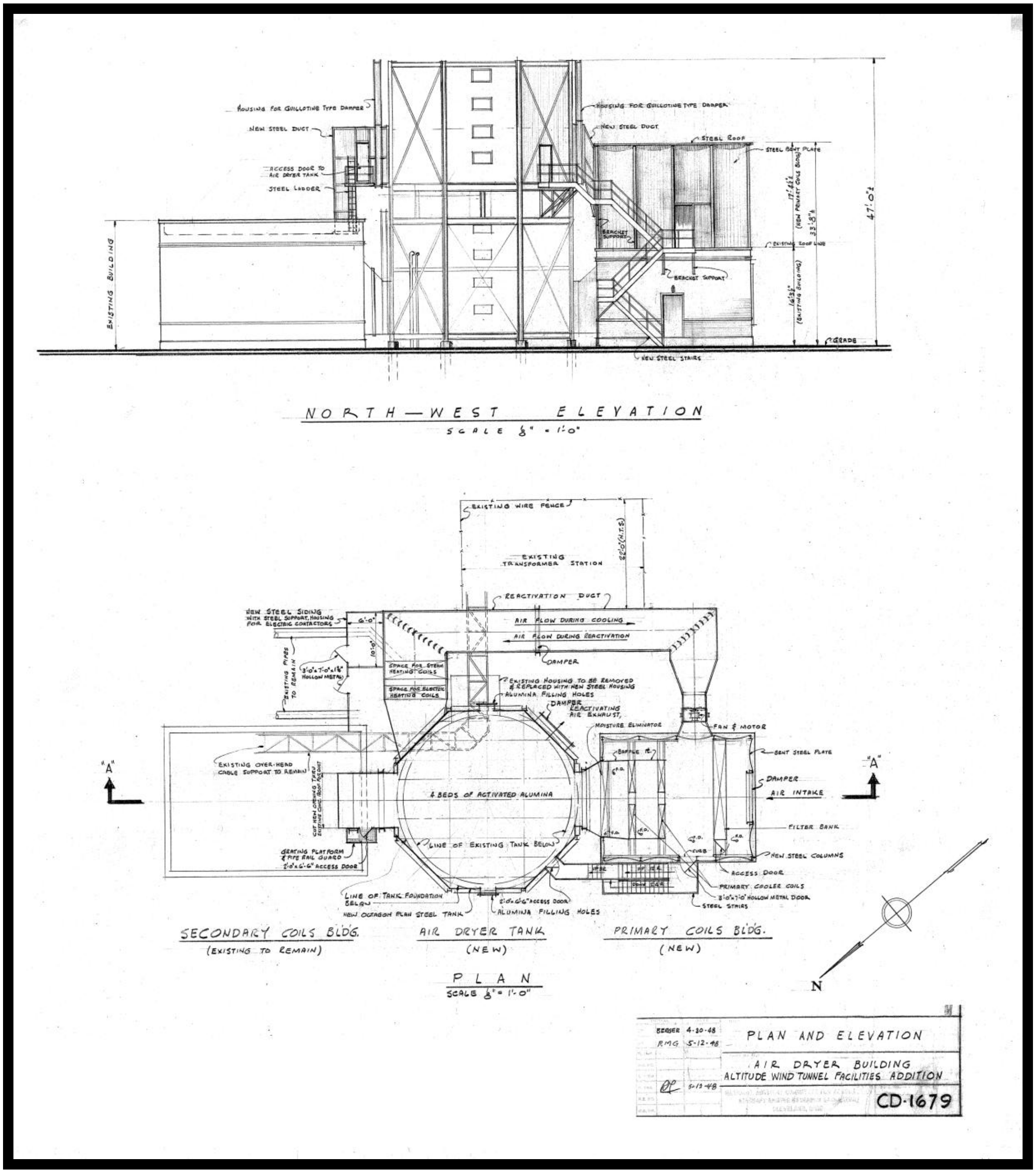
The alumina had to be reactivated between runs by running steam heated air in reverse direction through the dryer. It required approximately 5 hours to remove all the moisture from the alumina. The beds were then cooled by running chilled air through the dryer.[411]

The resulting cool, dry air was pumped to both the AWT and adjacent Small Supersonic Wind Tunnels Building through a 48-inch diameter pipe. The conditioned air was introduced into the AWT through pressure sensitive valves in two portals in the western tunnel wall. The southern 48-inch portal allowed some of the air in, but a portion was redirected through a pipe narrowing from 60 to 36 inches in diameter and was tied into the Refrigeration Building.[412] This uncontaminated air was then pumped from the refrigeration system into the tunnel upstream from the test section.[413]

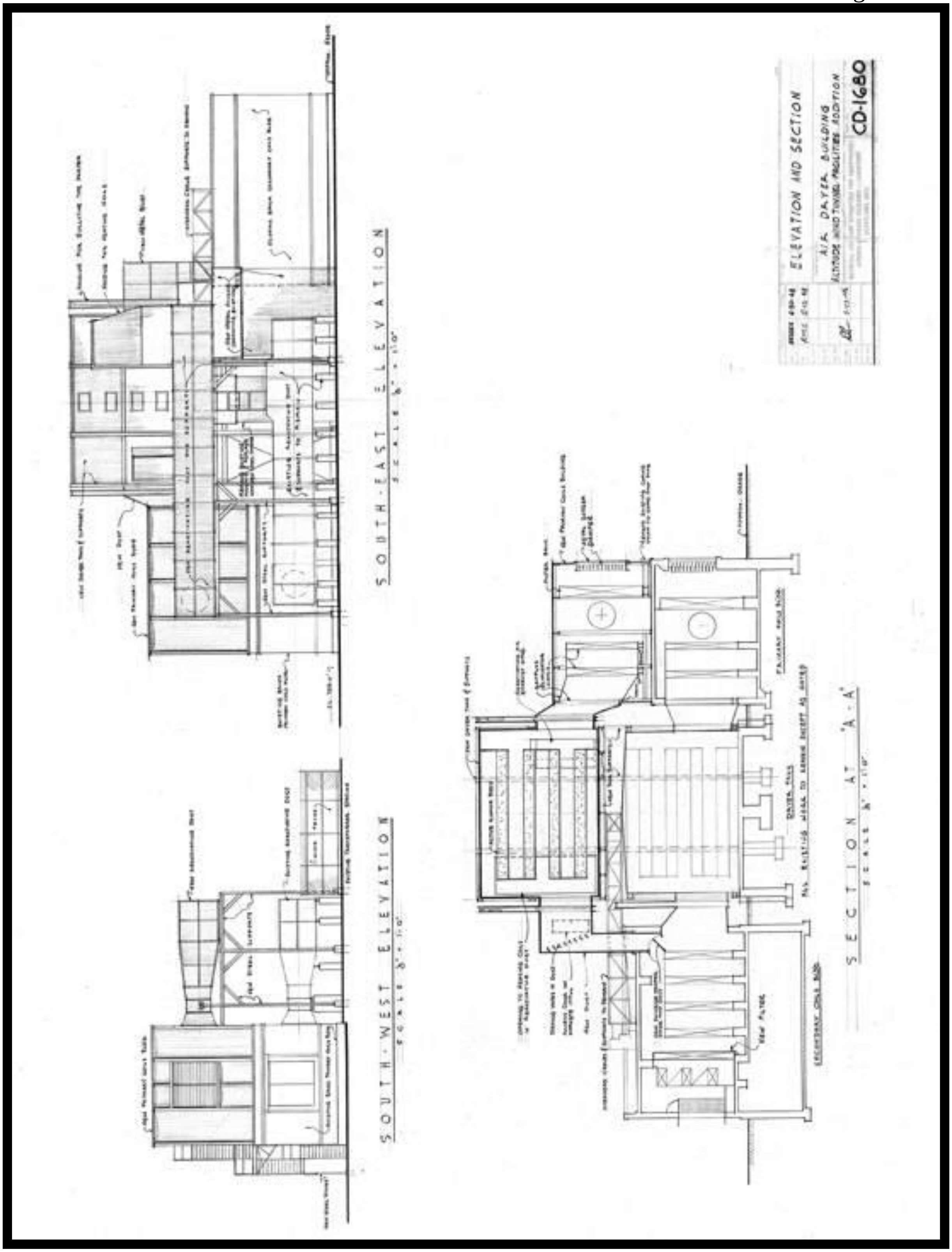
View from northwest of Air Dryer Bldg. after new dryer tank and primary coils were added on top.
Support Image No.78: 1955-39057/NASA Glenn Research Center
(1955)

During a 1948 upgrade, a new air tank was built on top of the existing tank and a new primary coils building built on top of the existing. The original duct was redirected to this upper chamber and a U- shaped reactivation duct connected the north side of this new chamber to the primary coils building.[414] It appears that the make-up air line directed to the

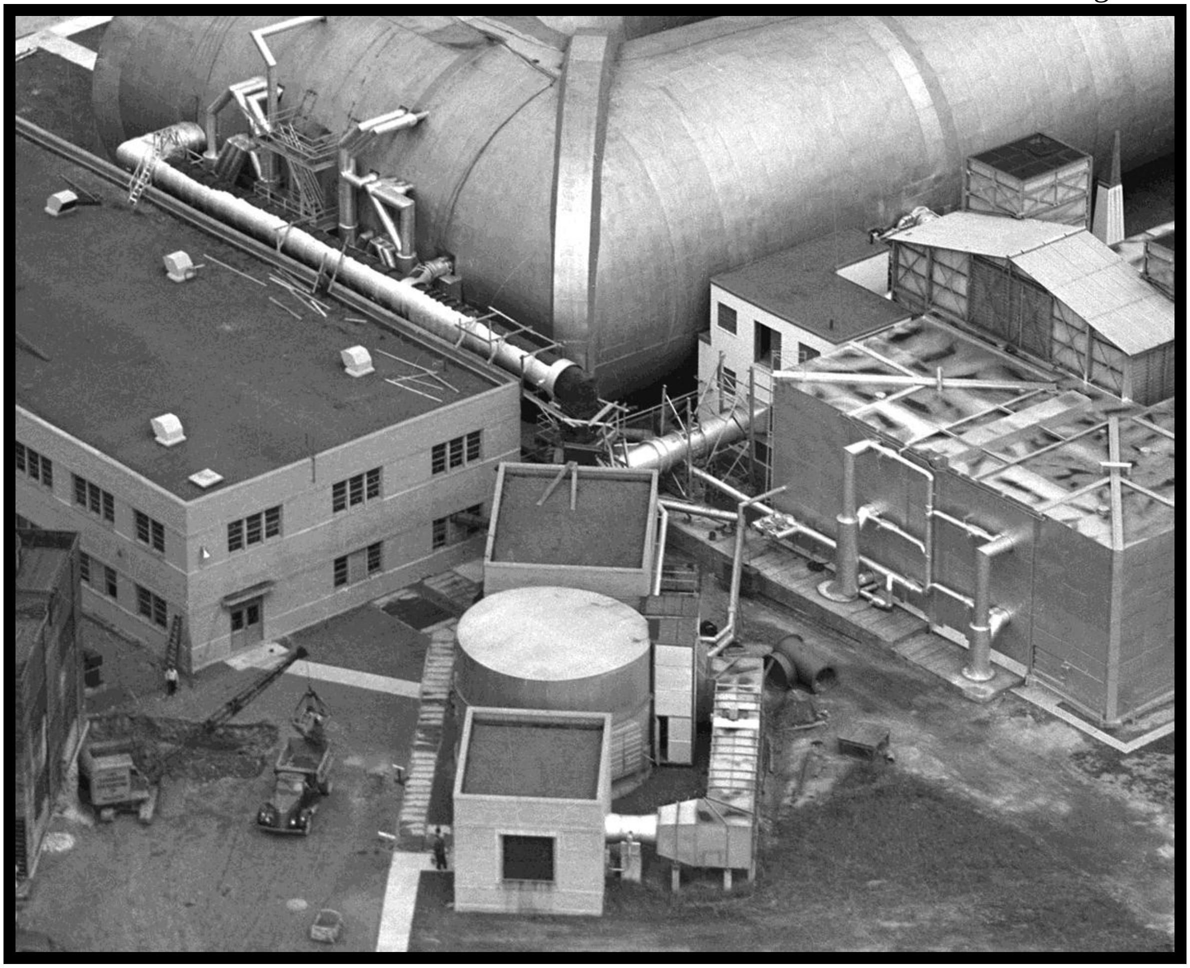
Refrigeration Building was removed in August 1985.[415] The air dryer tank then was demolished sometime prior to 1990. The Primary Coils Building became the Building 18-1, the Fire Pump Building. The Secondary Coils Building, 18-2, became the Gas Compressor Building.



Plan and Elevation drawing for Air Dryer Building addition
Support Image No.79: CD-1679/NASA Glenn Research Center (1948)



Elevation drawings of the Air Dryer Building
Support Image No. 80: CD 1680 01/NASA Glenn Research Center

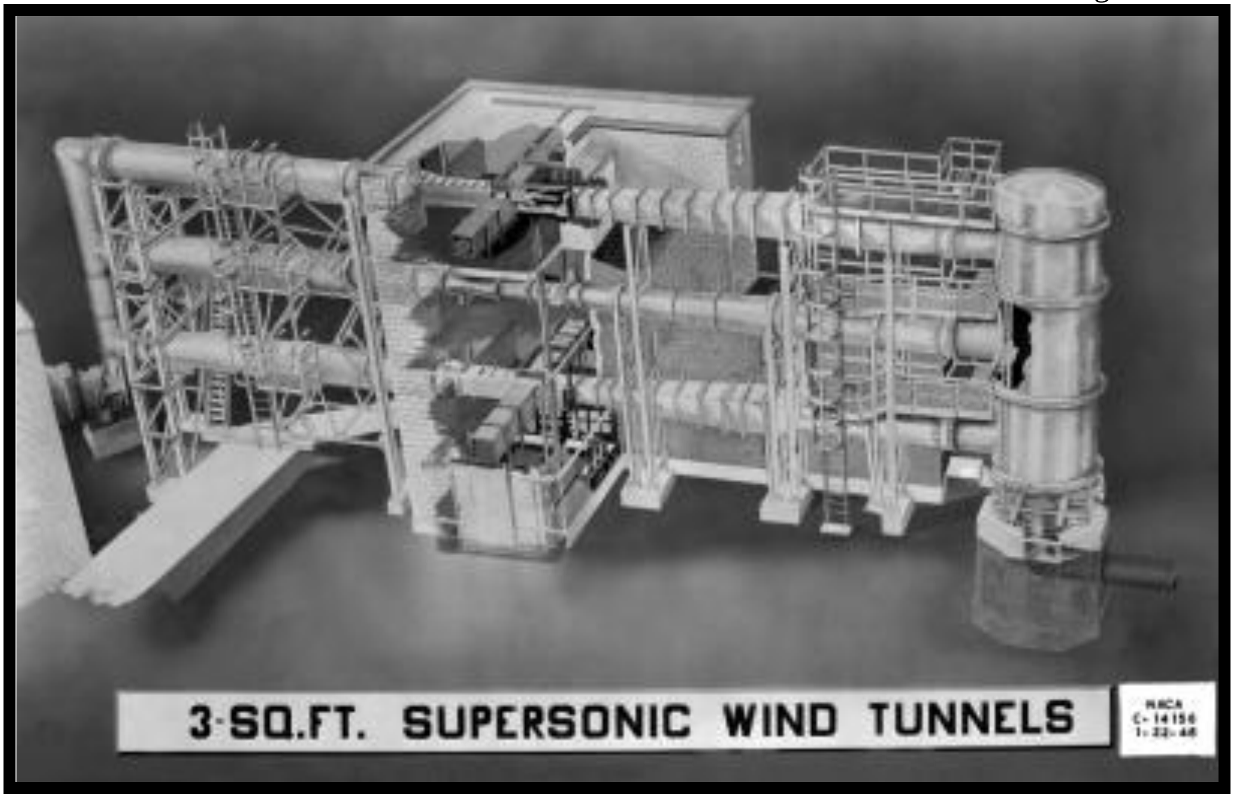


View from southwest of Air Dryer Bldg. showing air pipes feeding the AWT (l) and Small Supersonic Tunnels (r)
Support Image No. 81: 1945-13046/NASA Glenn Research Center
(1945)

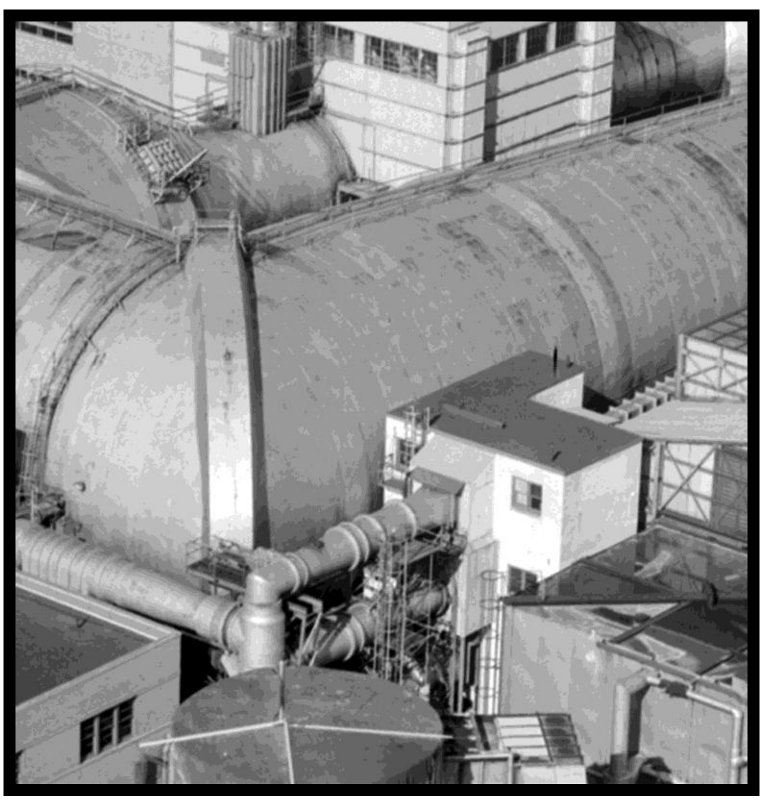
G. Small Supersonic Tunnel Building:

In the summer of 1945, the laboratory's first supersonic wind tunnel was built between the Altitude Wind Tunnel (AWT) and the Icing Research Tunnel. Two other supersonic tunnels were added vertically to this structure in 1949 and 1951. The tunnels were housed in an L-shaped building directly behind the southwest corner of the AWT. The building was informally known as the "Stack Tunnels" because of the three tunnels were aligned vertically.

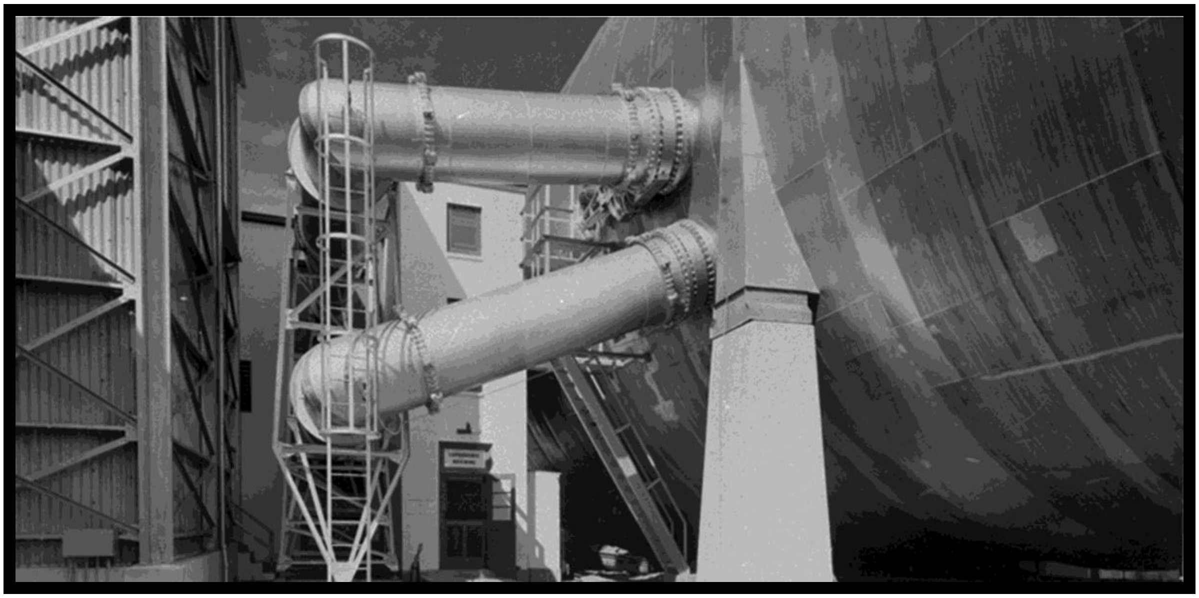
Because of the arrangement made with the local electric company, the AWT only ran during the night, so its exhausters sat idle most of the day. Abe Silverstein, who was Chief of the Engine Installation Division at the time, decided to use the AWT exhausters to create a small supersonic tunnel. He designed the 2.25-foot square open circuit tunnel. General Electric was hired in May 1945 to provide the drive motors and auxiliary equipment. The first tunnel was built in just 90 days.[416]



Isometric drawing of the Small Supersonic Wind Tunnels Building as envisioned in 1946
Support Image No.82: 1946-14156/NASA Glenn Research Center (1946)



View from southwest of the line from the air dryer feeding the small supersonic wind tunnels
Support Image No. 83: 1955-38653/NASA Glenn Research Center (1955)



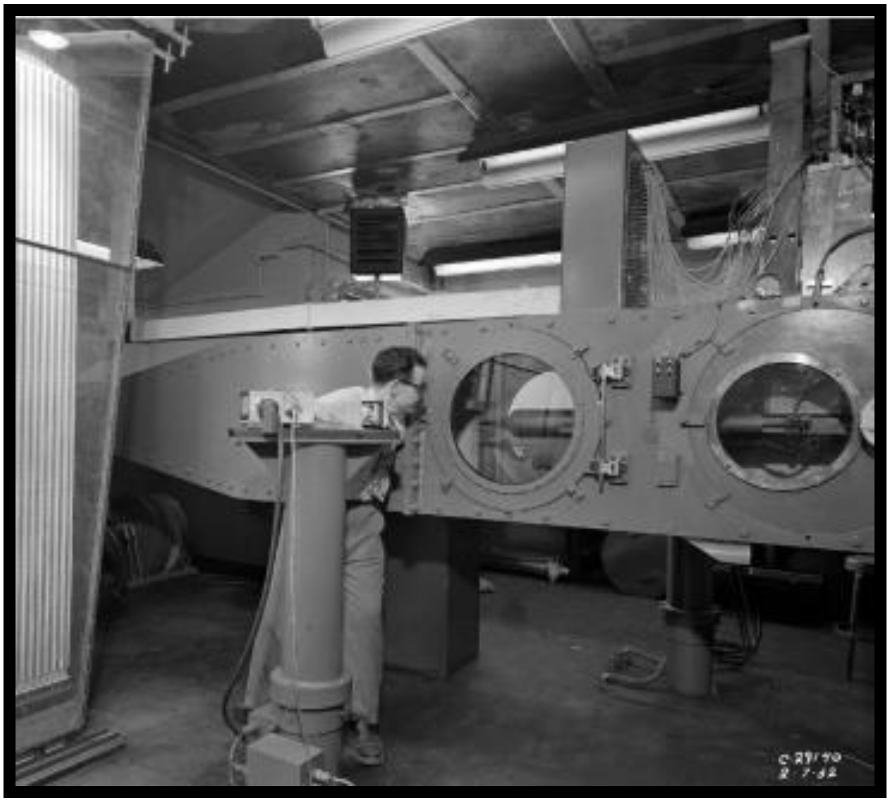
View facing west of small supersonic wind tunnels' exhaust tie-in with the Altitude Wind Tunnel
Support Image No.84: 1946-15686/NASA Glenn Research Center (1946)

The air flow for the tunnels was supplied by the AWT Make-up Air line. The line originated in the Air Dryer Building and was split at the southwest corner of the AWT. One end fed conditioned air into the AWT, and the other end traveled east where it was ducted into one the Stack Tunnels. After passing through one of the test sections, the 48-inch diameter exhaust line exited to the east then split. One section tied directly into the AWT's south wall and the other ran 125 feet 7 inches to the AWT's exhaust cooler. [417]

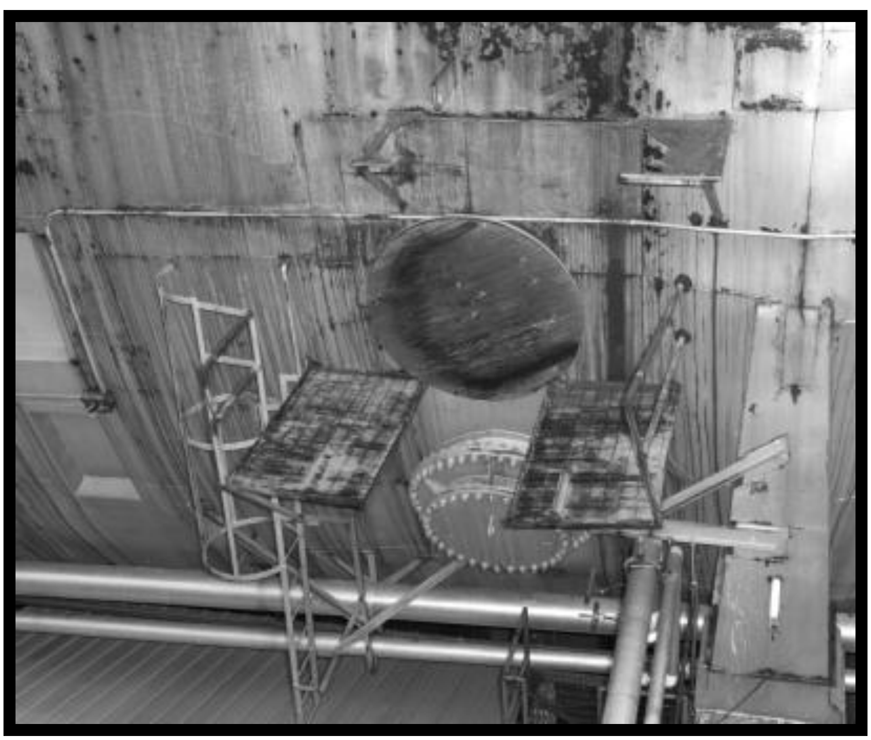
The control room was in the basement of the building with a large collection of manometer boards. Half a story above the basement was Tunnel No.1 which had an 18 by-18-inch test section and could reach Mach 1.91. Tunnel No. 2 was a Mach 3.96 tunnel with a 6-foot long and 24 by-24-inch diameter test section. The Mach 3.05 Tunnel No. 3 had a 4-foot long 18 by-18- inch diameter test section.[418]

Early tests in Tunnel No.1 focused on supersonic diffusers, supersonic ramjets, and supersonic aerodynamics.[419] In 1959 and 1960 tests included inlet studies for North American, light gas injection wing burning, and high-altitude rocket ignition for NASA. Tunnel No.2 was activated in September 1949 and included hydrogen peroxide fuel and gaseous nitrogen systems. The No.3 tunnel came online in July 1951. The latter two tunnels were used for North American inlet tests, NASA noise studies, and drogue parachute configurations in 1959 and 1960.[420]

Despite modest annual operating costs of $1500 for Tunnel No.1 and $3000 for each No.2 and No.3, the facility was deactivated by 1961 as the center became more and more involved with space. [421] The building was finally demolished in sometime between 1982 and 1987.



Ramjet model in the 24 b- 24-inch small supersonic wind tunnel
Support Image No.85: 1952-29140/NASA Glenn Research Center (1952)



Portals in south leg of Altitude Wind Tunnel where the small supersonic wind tunnels formerly tied in
Support Image No. 86: 2005-01675/NASA Glenn Research Center (2005)

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Endnotes

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